Architectural Document for a Dynamic Information Diffusive Network

Preliminary Version (Translated from Original Version 1.0 (2012.4.25))

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With the spread of the Internet, distribution technology for promotion of information distribution and search service technology for information gain have been advanced, and we are now able to obtain much content (valuable information for users as well as consumers) in less time. However, although the information distribution structure based on the value judgment by distributors is established in the current distribution services, ultimate value which is supposed to be received by users is not fully reflected. An attempt to gain feedback on the value by market research and user comments has been conducted. However, it takes time to reflect these results. The key to develop new business is how quickly distributors grasp values of the tastes of individual users and reflect them to their services. In order to do that, it is necessary for them to realize a ubiquitous structure around users by obtaining and analyzing network information and change it to valuable information on a regular basis and also to make it easy for new service providers to use as well. Currently, distribution service and information search service has been advanced as cloud service and information exchange among users via cloud service is also realizing. As it is now, however, users are required to purposely assign who to exchange the information with, and a structure to facilitate more flexible content distribution is also needed for future use.

Contents are widely distributed at the moment, but on the other hand, that has caused more serious network congestion than ever before. Even though higher-speed of core network or access network is used, a large amount of content that easily exhausts such network is distributed at once. Generally, content providers differ from network carriers, and moreover, the carriers commonly provide users flat-rate pricing for Internet access service. That is, as network carriers are unable to earn revenue from the development of content distribution, they have less motivation to increase network bandwidth. In order to distribute content without network congestion and provide stable services for users, a whole new system to effectively establish congestion-free network which covers both content allocation and its distribution, not using the existing networking equipment design methods to measure, analyze and forecast the network traffic and to increase in communication lines by equipment design. Especially in accordance with faster-speed and more sophisticated mobile terminals, it is an urgent issue to realize more efficient information distribution method including content in the access network.

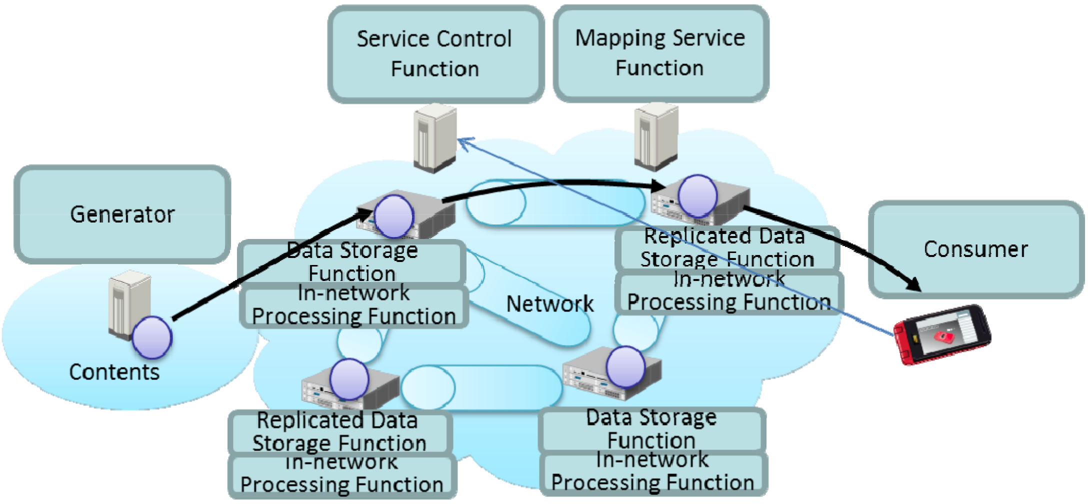
Here we propose a network architecture design that is appropriate for distribution of the information being constantly delivered from mobile terminals and/or devices from hour to hour (for some situations from minute to minute or even continuously). In particular this targets not only the way of mere information collection and/or exchange but also the information distribution network including a set of processes for providing users with value-added useful information. As of 2012, text and images can easily be uploaded from mobile terminals to twitter or other Internet bulletin boards. Moreover, users can pass along the various local information and provide the information for a particular region or event from different perspectives. With that we can obtain the latest information sent out and updated dynamically by accessing the network. For example, in the Great East Japan Earthquake in 2011, it is still fresh in our minds that most-up-to-date local information such as what is going on in the disaster area and/or traffic situation in the Tokyo metropolitan area was obtained from not only the overall information broadcasting from existing media including TV but also twitter. Even more in the future, it is expected that network information will further diversified by what people broadcast through their mobile terminals as well as widespread dissemination of so-called M2M (Machine-to-Machine) with the addition of the information from “machines” including temperature or rain fall sensor. In fact, a rapid increase in such network traffic is expected. The amount of the mobile terminal traffic in 2010 was 1-2 % of the total, however, it is now expected to be over 90% increase, compared with about 30% in fixed terminals like personal computers. It is also said that the M2M traffic will be reached to 300 petabyte per month by 2015. In other words, ever more information will be provided by mobile terminals and/or devices in the future. Information distribution network has a possibility to create unlimited value by distributing content including the valuable one generated from such diverse information.

Information distribution network targeting in this paper has the temporal merit to provide a content delivery service in a shorter time than before by appropriate information allocation to the network and information delivery to users via appropriate services. In addition to that, delivery of a new service to obtain necessary content without purposely assigning who to exchange the information with over the network becomes available with a radical change in interface between users and services. As a result, users do not need to search the latest content through the Internet search service by themselves. With dispersed content placement and its conversion process which is suitable for user's current environment, it also enables the realization of user-centric services avoiding the server bottleneck. Furthermore, the content delivery service with new values can be realized by the process of combining a large amount of information with content. For network carriers, on the other hand, they could include such service platform as content delivery and M2M services in their businesses and conduct infrastructure development that is linked to those services. This is going to contribute to the equipment enhancement cycle which gives much advantage for users. For service providers, they could also realize the cost-advantaged network that can drastically reduce costs for communication line or storage equipment and/or resource placement operation.

Information distribution network also has an advantage in power consumption as well. Although the cost for storage to store information is becoming cheaper, it is actually limited, and at the same time it is essential to deliver and exchange information for the realization of the services. The problem is that entrusting content distribution to each service provider causes a significant risk of enormous energy consumption. There is a high possibility of controlling power consumption by appropriately managing content allocation/distribution on the network side. In this paper, with this possibility in mind, we establish the lifecycle of information. As stated above, in order to support the advance of additional human knowledge and wisdom and build the information network to generate new value, it is important to make information distribution efficient and establish the mechanism of new information distribution focused on the information value. We realize the information distribution network as high-value added platform for new services toward the construction of the value-added information distribution network business in 2020. For that, as pointed out above it is essential to clarify stakeholders and to introduce the competition principles, and the network architecture to support the mechanism of new information distribution based on such viewpoint.

Here we clarify the vision and its design goal for the realization of information diffusive network (hereafter "Dynamic Information Diffusive Network"), which processes dynamically-generated information from users or devices regardless of fixed or mobile one when needed, and propose its design principle. In our information diffusive network, we realize the provision of platform and infrastructure for newly value-added services such as M2M and content delivery with future growth potential, and at the same time, we realize operational cost reduction in these services and network. Therefore, we design the network which realizes an efficient access to the dynamic information, in-network processing suitable for content creation with an addition of its distribution and value, simple mobile control, efficient information distribution and energy use. These can also be a new network suitable for the four purposes for future network, i.e., service, data, environment and awareness for the social and economic aspects, defined in Recommendation ITU-T Y.3001 [1]. With a goal of that, per network carrier, one billion mobile terminals and 100 billion sensors and actuators are stored, and 100 milliseconds for data access and 1000 times more efficiency in energy are set. Also, as enabling technologies, we refer to the new technology for information collection from supermass devices and mobile terminals and a volume of content management, not to the expansion of the current existing Internet technology. As a guideline for the future network design, we moreover refer to the function framework for information distribution from the point where information arises to the one it is received by users. In order to show the comparison of the current Internet technology, we describe functionality and efficiency of the dynamic information diffusive network, compared the Internet that Information search service or content delivery service is independently provided, not by network provider, with the framework and functional layout example of dynamic information diffusive network described in this paper. (Below figure shows the functional layout example).

We hope this paper will be a help to provide new guidelines for information distribution in the new generation network.



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1. Introduction

1. 1 Information Value

Content (meaning of valuable information for users as well as consumers) distribution and delivery service technology and search service technology for information gain have been advanced. We are now able to obtain much content in less time accordingly. Currently, a large volume of content on what requires less update frequency such as image, music, science data, and etc. has already been distributed in the Internet and as a result of the development of technology, the advanced delivery service enables users to quickly obtain content, even large-sized one, with less stress. For information search service, on accessing to the search server, we can obtain a list of location information of the content based on the sequence in accordance with general taste or a server's policy. As it is now, therefore, information search service providers establish database with a huge amount of content location information on the web server by crawl. These services have further developed and been advanced as cloud services. Personal information such as emails and electric files now tends to be saved in data center. In other words, providing access to information through applications including emails or electric files is a service. Information exchange among users over the cloud service is also realized. Information generates value for users by the delivery through various network services. However, resources spent for the transfer of information with equivalent value do not stay constant. For example, according to [2] [3], it is shown that information unit value (of traffic amount in bit divided by amount charged to users) per byte varies greatly depending on mobile packet services (mobile email, data, etc.), mobile phone calls, fixed-line phones or fixed-line Internet access. This case considers the amount that users pay for services (information transfer) as information value. Comparing a use of data in mobile service with the one in fixed-line Internet access, approximately four-digit difference can be seen in its unit value (Fig. 1). Moreover, there is also a four-digit difference in the comparison with the total traffic amount of a contractant monthly use. Although it is not easy to simply compare email-use-only services with other data transfer ones in such unit value or total traffic amount, comparing the use of email with the use of fixed-line Internet access service in mobile services, there are about eight-digit difference in its information unit value and about seven-digit difference in the total traffic amount. Based on the network service provider’s standpoint, it is necessary to set up an appropriately-managed network in information location, which considers both fixed-line Internet access service with low unit value and mobile service with high unit value. It is also necessary to distribute information more stably in the network service with high unit value.

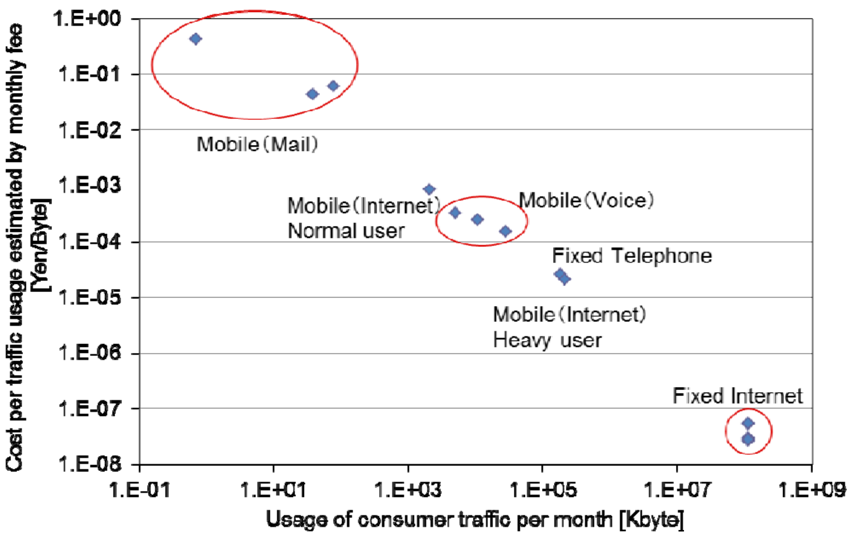

Fig. 1. Relationship between Information Unit Value and Traffic Volume of Network Service

Meanwhile, the power consumption for transfer or holding of information in the network field has already exceeded 50 billion kWh in 2005 [4]. As long as the earth's finite energy is utilized, a network design with consideration for a limit of power consumption is required. Although the power saving of the network equipment is a major issue and various efforts are currently undertaken, the issue here is how to promote improvement of utilization efficiency of power consumption in the content distribution. As described above, there seems a lot of potential to drastically improve utilization efficiency of power consumption by appropriately managing the resources for the information location and its distribution on network side. For energy efficiency, it is essential to consider limitation of power consumption and establish the information diffusive network enabling to maximize the information distribution value.

In the current existing content delivery systems or search engines, timely and efficient upstream information transfer has not been realized yet, and also downstream transfer has been optimized for the times to acquire the latest information neither. As will be described in the following section (1.2), data volume such as lively generated data (data here means what requires analysis or seems no good enough value for users like sensing information from sensors or information broadcasted without reference to the users' want value.) from mobile terminals will increase and accordingly the number of the sensors sending dynamic data will increase substantially. With the rapid future development of this field, more frequency in connection to and disconnection from the Internet can easily be pictured. Considering the data transmission from devices as upstream data transfer and the information on users' data reception as downstream data transfer, the upstream data with mobile terminals or M2M communications will rapidly increase and become dynamic in the future. Here we intend to establish the information diffusive network that matches with the needs from both users and services regarding how to possess value as information and distribute information effectively.

1. 2 Fact Data and Its Analysis

This section shows the estimates for the traffic amount in 2015 of the M2M communication with rapid future growth potential, in which an object to generate data (for example, sensor devices for camera) moves with its generation and does communication across several network domains in the process of its movement. According to [5], security and monitoring of businesses and consumers, healthcare, vehicle dispatch, inventory control and telematics are included in a service with large-capacity M2M traffic.

Estimates for mobile data traffic in 2015 are shown in Fig.2 [5]. According to the estimates, total mobile traffic in 2015 will become about seven exabytes per month. Of this, the traffic generated by M2M devices will be 4.7% of the total and reach about 300 petabytes per month. This figure is estimated to exceed total amount of the whole mobile data of 237 petabytes per month in 2010. According to [6], total IP (Internet) traffic in 2015 will be 80.9 exabytes per month and the ratio of mobile traffic and fixed-line (non-mobile traffic: the amount taken mobile traffic from the total) is one to ten. Therefore, with an easy estimate, the traffic for movement of sources will be about 30 petabytes out of the monthly M2M traffic of 300 petabytes.

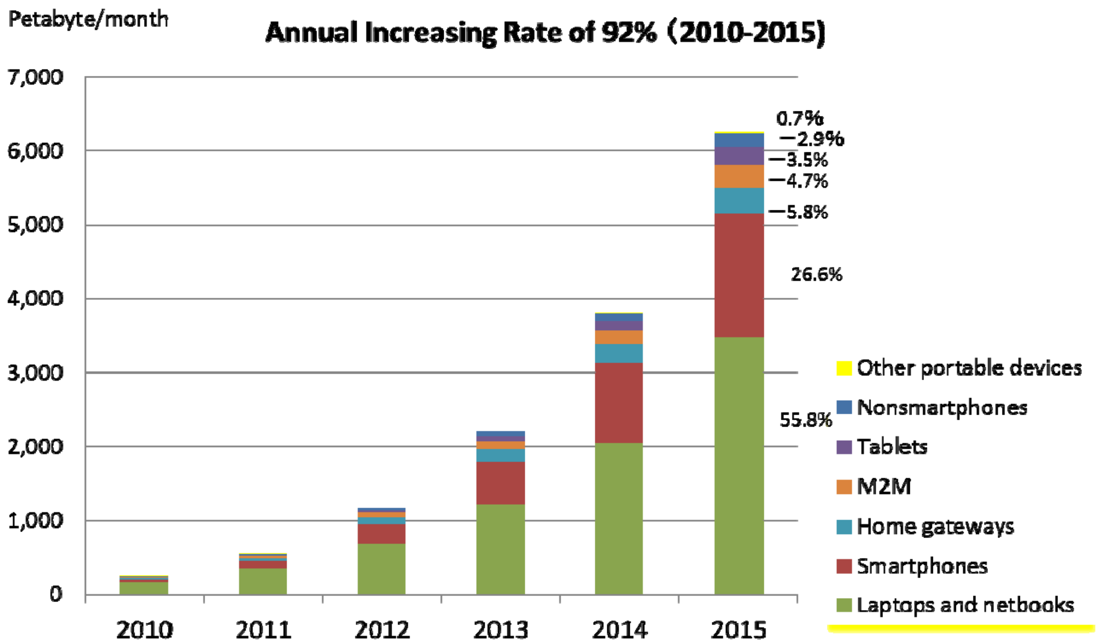

Fig. 2. Trend for Mobile Traffic and Its Breakdown (created with data from [5])

2. Social and Economic Effects

This section describes the features of the dynamic information diffusive network architecture and the effectiveness of its architecture establishment viewed from the social and economic aspects. Dynamic information diffusive network with a different structure from the current Internet and the information distribution services in the Internet brings new stakeholders and business development by a creation of the business model that allows a small start for new services. Behind the social and economic effects, high-value added network platform with benefits to both network carriers and users is constructed.

Followings are the three outlines for social and economic characteristics and its effects (Fig. 3). These are also used for the examination of Design Goals (Section 4) and Required Technologies for Protocol Design and Implementation (Section 5).

• Clarification of stakeholders and introduction of competition principles

In the dynamic information-diffusive network, necessary network and service resources are allocated to the right place through proper analysis of qualitative and quantitative characteristics for information distribution. The stakeholders are clarified by establishing hardware specifications for the equipment that operates them in an optimal way as well as the network control mechanism. Also the competition principles possible for newcomers are introduced.

Specific examples for characteristics are as follows:

1. Characteristic for generators (those who generate information): who, when, where and how much to generate.
2. Characteristic for consumers (those who consume information): who, when, where, what/which and how much to obtain.

Taking the existing content distribution service for example, “who” in the above 1. can be content providers and in the above 2. can be users who purchase content from the content providers. For sensor data distribution such as M2M, “who” in 1. can be owners of the sensors and in 2. can be users of the sensor information. With clarification of the characteristics for such information distribution, the stakeholders who provide various functions for information distribution could make themselves clear for what to provide and could also investigate the appropriate allocations of network and service resources they provide and/or utilize. In the case of the existing content distribution, content providers, users, search providers to conduct matching for between the two, network providers to provide data transfer between the two and distributors to allocate compensation from the information distribution are at least required.

For the case of the dynamic information diffusive network, “who” in the above 1. can be owners of the sensors or mobile terminals and in 2. can be the users of content. The role of mediators in intermediate service composition function and its information allocation will have a larger impact on improvement in the network quality. Moreover, in order to introduce the competition principles possible for newcomers, the dynamic information diffusive network needs to be improved in the interoperability among function and simplified in the provision of each function by the stakeholders.

• Construction of the value-added information distribution network business in 2020

There has to be several business models for the new generation network realized in 2020. Realization of the early prototype in 2015 and development of the network business in 2020 are planned. Specifically at first, taking content distribution for example, the early prototype will be realized and the superiority over the current existing content distribution will be clarified. Then a business model consistent with the simulated information distribution in 2020 will be examined.

In the current existing content distribution (for example, search content with Google and download it from Akamai), the content (image, music, science etc.) is static and rarely updated once placed. Meanwhile, it is said that in the near future dynamically-changed data and dynamically-synthesized content from the data will increase. For example, changing data means the dynamic information frequently broadcasted from moving people or vehicles, the data (sensor data) dynamically sent from sensors, or the fixed-point observation data sent from various hosts who pass through the fixed-point. Also, the current existing content distribution covers a relatively wide content in its region say inside Japan, however, the new distribution is targeted even for more limited areas with an idea of local generated-data/content for local consumption as well. With the information distribution in 2020 and the new-service aware network designs, a business model that can promote a small start and the healthy development for the promising new services will be developed even if the existing service dominates the market.

• Construction of high-value added platform for new services

A platform for diffusion of the dynamic information as well as of the existing piped transport networks will be established and an environment producing high-added values will be developed. In other words, with efficient information distribution management and no content crawling, the network architecture with certain advantages to network carriers in terms of bandwidth, power consumption or operation and also to users in terms of service response time or user interfaces will be established. In particular, the network (service and infrastructure) in which data is sent dynamically from terminals or devices will be established. In some cases, moreover, the network that asynchronously distributes data with change in the location of information transmission or change in the source to send information accompanied with movement of mobile terminals, forms the content in the network and distribute to users will be established.

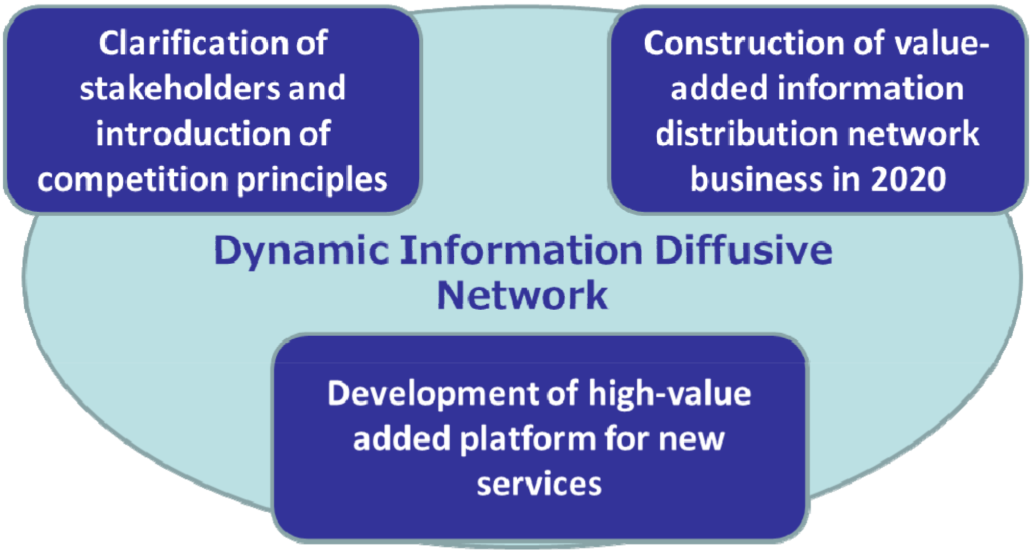

Fig. 3. Dynamic Information Diffusive Network for Social and Economic Effects

3. Visions and Network Design Principles

In the dynamic information diffusive network we are realizing, we work on the development of new values by efficiently distributing data that is generated and dynamically sent from various sources like mobile objects. This is set as a vision for the dynamic information diffusive network. This network realizes the provision of platform and infrastructure for newly value-added services such as M2M and content delivery with future growth potential, and at the same time, realizes operational cost reduction in network itself or these services.

Following are the five network design principles to achieve dynamic information diffusive network with core elements for embodying the vision. The outline is shown in Fig. 4.

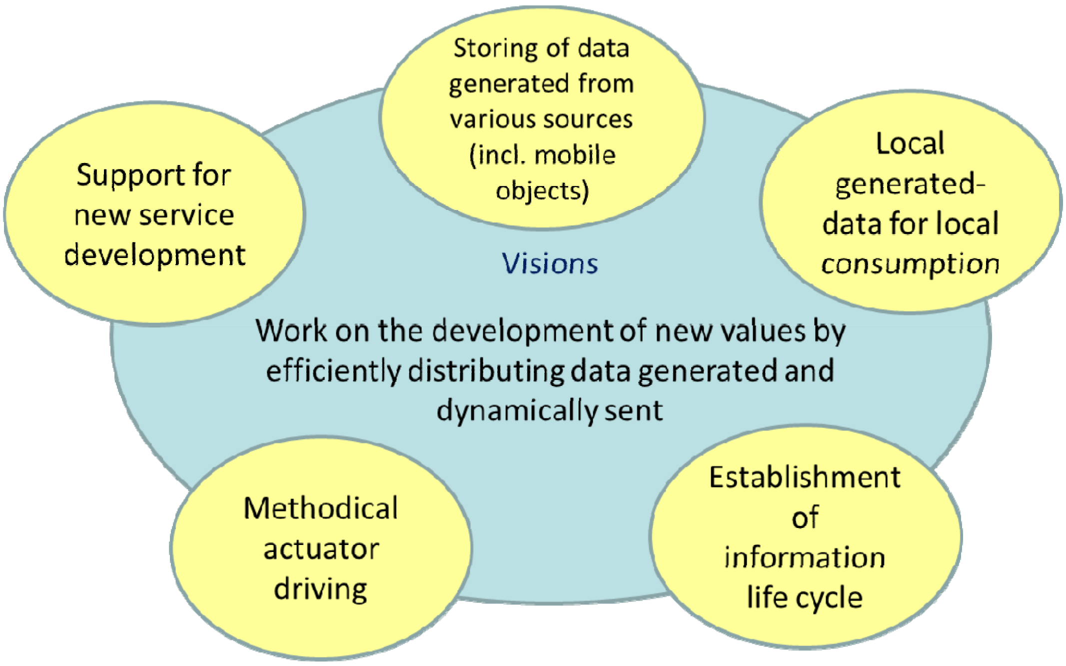

Fig. 4. Visions and Network Design Principles

- Smooth storing of data generated from various sources including mobile objects
Sources of M2M data are ubiquitous in the real world and generate data at their own timing. As previously described, these sources come from the mobile objects such as a person or vehicle at a rate of about 10 percent. And the data makes frequent and erratic changes according to the change in the real world. In such an environment, it is difficult to predict when and what kind of data will be generated from which sources, and it is necessary for networks to identify the source of data for intended data acquisition and provide a function to figure out the means of effective access to it. The dynamic information diffusive network realizes a smooth storing of a large amount of data that is generated all over the network and delivered dynamically, as well as an easy access from users and services.

- Local generated-data for local consumption
There is a lot of information with locality included in the data from the source due to frequent access from the neighborhood. With that, it is not efficient to transfer and compile all the data in one place on the network e.g. data center from the aspect of the traffic amount or communication delay. Dynamic information diffusive network establishes the information distribution that realizes an idea of “local generated-data for local consumption” by placing the generated data to the network access points or edge nodes and also prevents network congestion as well as delay in data transfer caused by information distribution. This will bring big impact on power saving of the whole network.

- Establishment of information life cycle
While a large amount of data is constantly generated in M2M, most of them get lower value in use after a cer-

tain period of time and then even useless at the end. The same goes for the content in terms of change in lower value in use. On the other hand, resources of data accumulation and communication necessary for the realization of access from users or services are limited. And therefore, it is important to keep the redundancy of largely-distributed information and to establish a structure to transfer intended information with consideration of total cost. This was actually difficult to realize in the independent content distribution service. The dynamic information diffusive network establishes information distribution based on the efficient information life cycle by widely spreading valuable information and sprinkling or deleting unvalued one.

- Methodical actuator driving
  The data generated from various sources and stored in networks is used not only by users or specific services directly but for creating scenarios that drive various actuators accurately and cooperatively. In other words, the method being described in service scenarios based on the data drive an actuator, and individual data contributes to the creation of an enriched society and the industrial advances. With effective information distribution, the dynamic information diffusive network realizes a support function to handle the stored data in the network and also methodically drive actuators based on the data.

- Support for new service development
  In order to promote the development of new services which utilize interaction with the real world, it is important to support the growth for market needs in these new services. It is also important to support the healthy development for the promising new services even if the existing service dominates the market. For example, supporting a small start for the content distribution business with a platform of the existing services such as cloud or shared use of sensors or actuators by several services can be considered. With establishment of information distribution, the dynamic information diffusive network realizes a support for such a new service development.

The dynamic information diffusive network established based on the above described visions and design principles take in the basic services in the current internet as a platform. For example, it provides networks or services with an advantage in information unit value without crawling, energy consumption or service response time as well as specific examples of necessary functions. Here we show an architecture realization framework served as a basis for building of a network in Section 6 and specific examples of Network CAPEX estimate as part of feasibility in Section 7.

4. Design Goals

This section describes new perspectives and design goals along with numerical targets for the dynamic information diffusive network. The design goals are realized based on the visions and network design principles shown in Section3, considering the social and economic aspects shown in Section2. The relationship of the goals and design principles are shown in Fig.5.

(1) Efficient access to dynamic information including sensor information

Information sources are ubiquitous. Therefore, it takes a lot of work for users requiring information to identify the place of the information source or the device. Not just knowing such location or name, there could be a possibility of network access disruption or even no interactive communication. For constant acquisition of information, it is necessary to save the information sent from devices in an accessible place on the network and compose the network that users can quickly obtain data from it. Simulating the information distribution configuration mainly focused on sensor devices and mobile terminals as its information source, the composition that can quickly save the information acquired by them needs to be ensured. For that, it is necessary to simulate to store the data once in a temporal saving location in a network before moving to the final save location. Also, holding of the appropriate information needs to be ensured even if entry point to the network is changed due to the movement of mobile terminals.

At a time that mobile terminals acquired information, more data acquisition by the mobile terminals around the entry point could be considered. Moreover, depending on the requirement of information acquisition from other mobile terminals, efficiency in information access from the terminals by dynamically making an optimum placement of information saving location will be ensured. Information access time from mobile terminals is designed to set to less than 100 milliseconds.

As for the information acquired from mobile terminals, the search efficiency in information use by making an appropriate meaning and connection will be improved.

In terms of the total number of mobile terminals and devices, a design to store one billion mobile terminals and 100 billion sensors and actuators per network carrier will be ensured. Also, a design that enables to control appropriate traffic amount with considering an accelerated demand in traffic due to disasters or use in events will be considered.

(2) In-network processing suitable for information distribution and content creation

In order to make information distribution efficient, cache and storage functions in the network to hold the information are placed. Moreover, a platform which can place the various information processing functions in the network and synthesize several new information in order to create value from the ubiquitous information is composed by the resources in the network. With this platform, for example, contents conversion matching with users' communication environment or contents synthesis matching with users' tastes can be conducted in a timely manner.

(3) Simple mobile communication control

A network that is suitable for storing data from mobile terminals or devices with low functionality/low performance is composed. A network that controls simple mobile communications without a bottleneck of distribution, not expecting communication environment for the terminals and devices or their sufficient processing abilities is set up. Mobile objects are not limited to its terminals but include storage or cache with broadcasted data and others such as service mobility for the avoidance of congestion and DDoS attacks in a network.

In this regard, for the network management, the control and authentication for information of a billion mobile terminals and storage devices, registration in the movement of services and its smooth management need to be simplified. The independence of identifiers for management by location or service unit also needs to be remained.

(4) Efficient information distribution and energy use

A network that promotes information distribution by a structure centering on information, not the one centering on the place for storing information is composed. On this occasion, in order to save time for users to acquire information and reduce the amount of functions or energy consumption, the resource smoothing and the improvement in utilization efficiency in terms of effective bandwidth or energy by a resource placement or technique in communication are planned. For example, with a design focused on the data or content distribution, the network that enables the reduction of unnecessary information transfer or the smoothing of traffic by promoting efficiency in information transfer to control the maximum bandwidth by dispersion of the information distribution channels and the peak traffic in temporal information storage is composed. 1000-fold improvement in energy-use efficiency compared to the current one is set as a goal.

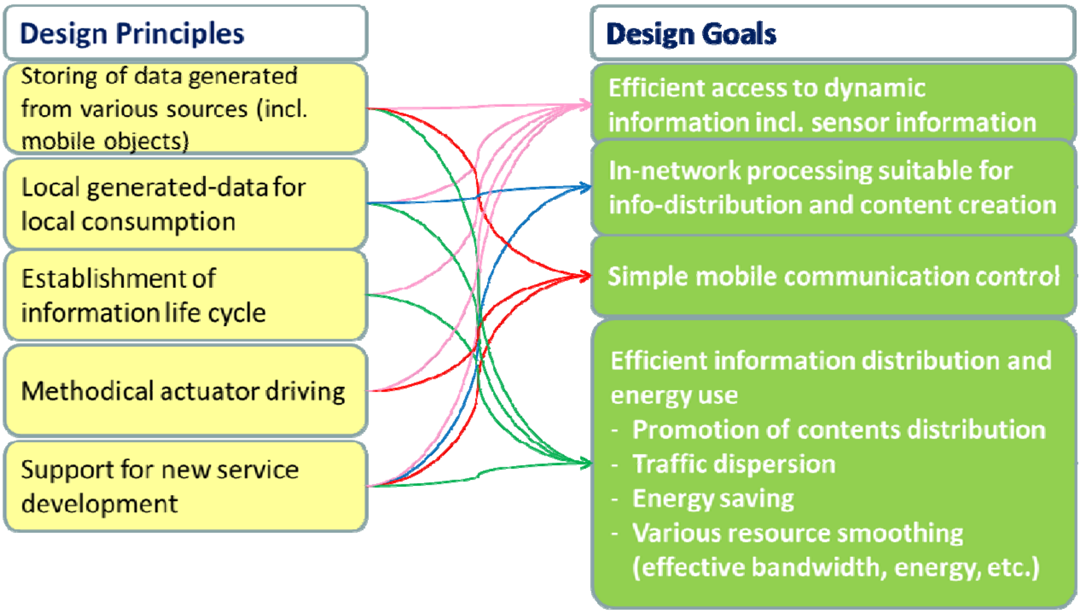

Fig. 5. Design Goals and Its Relationship with Design Principles

5. Required Enabling Technologies

This section describes the enabling technologies, which are necessary to realize the design goals shown in Section 4 (Fig.6). We do not go into the details of the technologies here but indicate the direction of its summary only.

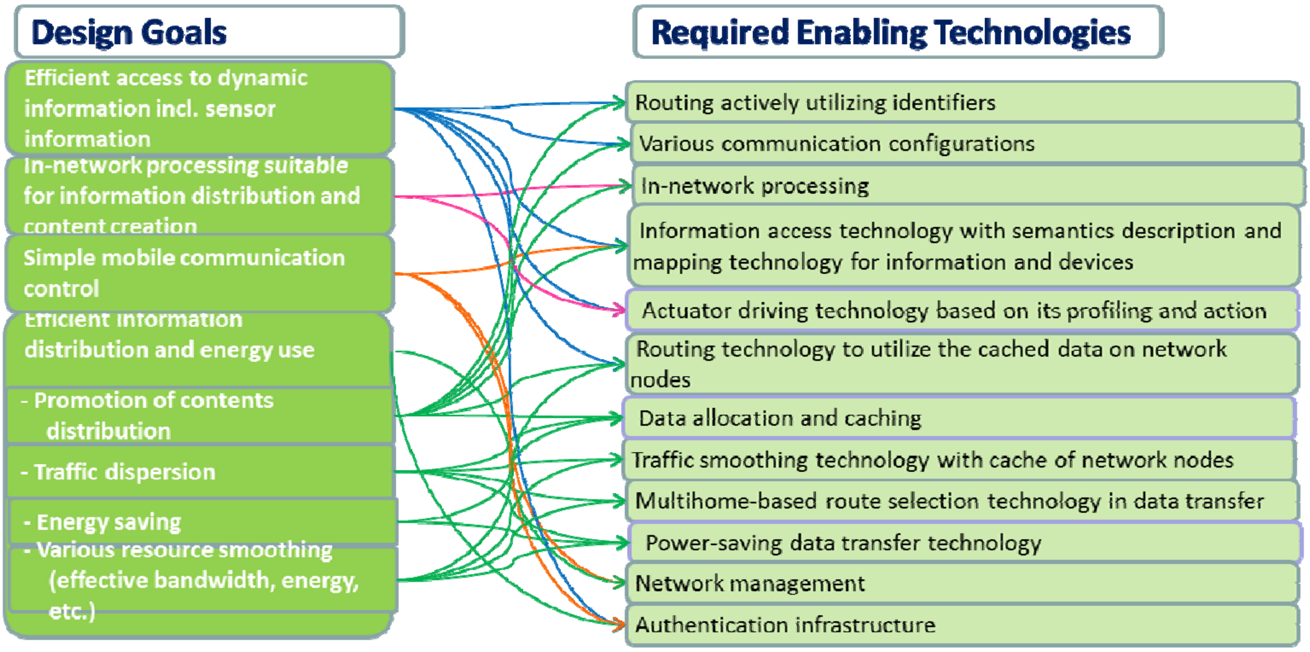

Fig. 6. Required Technologies and Its Relationship with Design Goals

- Routing actively utilizing identifiers

  When ubiquitous information sources including mobile objects in the real world generate data irregularly, it is difficult to grasp the location of data. Accessing to data being sent dynamically, an access terminal needs to designate an identifier (ID) for the intended data, terminal with data or node for network routing, not designating an address depending on the location of the data (Fig.7). This enables an easy access for the terminal to data without being aware of moving data or changing address of correspondents. This kind of feature has a beneficial effect especially on the M2M terminals without advanced functions. For example, the technologies proposed in [7] - [13] have a potential to be applicable for routing with identifiers.

  Furthermore, the current network involves the need for a dynamic routing-change in response to the movement of virtual servers, load dispersion of servers, network congestion or change in the system operating condition. Utilizing identifiers actively even in this situation enables a flexible change in data transfer in the process of its transmission, an easy network optimization and reduction in operational costs. Identifiers being used in network will be described in Section 6.

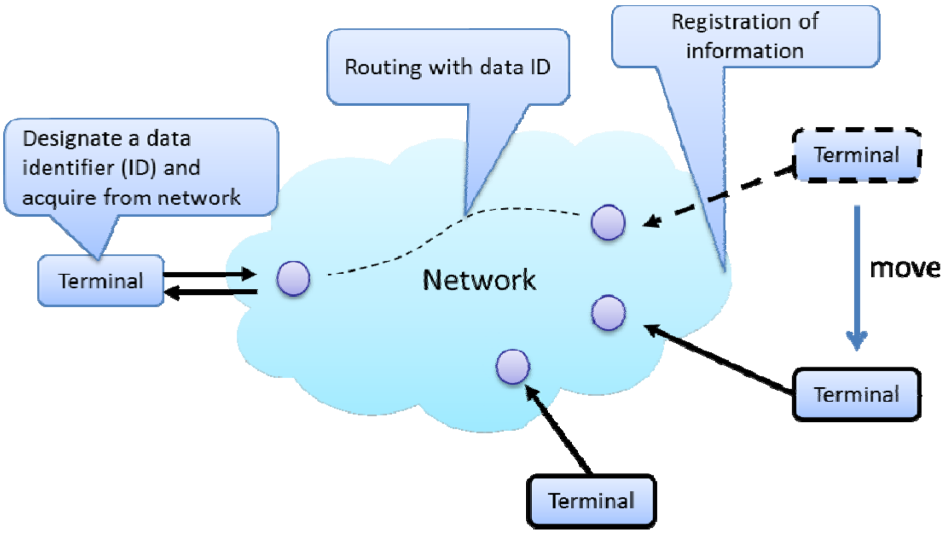

Fig. 7. Routing with Data Identifier

- Various communication configurations

  In the existing network, the terminal-terminal one-to-one communication (unicast) is a mainstream. In M2M or content delivery, heavy uses of broadcast or multicast, publish/subscribe-oriented communication [14] and query-oriented communication are expected. This enables data sharing among a large number of users or asynchronous communication. For example, publish/subscribe-oriented communication is suitable for the sharing of data with non-regular updates as it is directly broadcasted at the time of its update to those who subscribe a specific data. In order to realize this kind of communication, an advanced function is required for the communication node in the network. For example, publish/subscribe-oriented communication requires functions not only for the current routing and data transfer but for subscriber management, creation of distribution routes and data replication.

- In-network processing

  With analysis of various and much sensing data, a service utilizing interaction with the real world realizes high quality of experience for detailed situations or tastes and it creates a new business market. In the current network, nodes only transfer data, and the processing of sensing data is run by end host, more specifically by server in data center as application-specific transaction. In the future network, due to the diversity of terminals or services and the increased demand for knowing what is changing in real time, it is important to have the network processing function to process the ubiquitous data with the nodes in the network or the server equipment adjacent to them. Load reduction in the primary processing of application data, efficiency in data transfer for "locally generated, locally consumed" services or reduced response time are expected in in-network processing.

  Rule matching and statistical processing can be taken as an example of in-network processing. Rule matching is technology to conduct detection of the data or event necessary for applications in real time and it can classify the specified rules into stateless or stateful. A stateless rule includes data detection with above threshold level, specific value detection or a combination of those, and it is also realized with use of the technology such as distributed hash table. A stateful rule, on the other hand, is more complicated, which enables the description of the temporally-continued event. Generally, the description of rules and the architecture for distributed processing are researched by the technology called complex event processing (CEP). Statistical processing is technology to process a large amount of sensing data statistically and detect its characteristics in real time. These features enable to generate effective data for higher level of information processing for applications such as trend and characteristic of largely generated sensing data with in-network processing.

- Information access technology with semantics description and mapping technology for information and devices

  Toward the creation of the open IoT (Internet of Things) services market and the realization of more advanced services, it is important to achieve the application operating environment that enables to acquire and operate the real world situation through abstracted interfaces in order to easily provide the advanced and flexible IoT services with a number of different sensors or actuators. Therefore, “Interpretation”, a function to convert events/things expressed by semantics to the information (data ID/content ID) is required.

Furthermore, there is also a function required for mapping of the node ID being added to the network node that stores the device or data from the information identified by data ID or content ID. As its design requirement, mobility needs to be considered. In the existing network, as a form of mobility, both handover to realize the geographical communication for terminals or the continuous communication for movement between different wireless media and nomadism to enable intermittent access from different places to the network are realized by the mobile access network, LAN technology, Mobile IP and others. Meanwhile, in the IoT environment, for example, as in the case of sensing of the fixed point of data by different mobile objects, it is necessary to consider the case where the device generating the same information is switched over and the information life cycle in the network including copy or delete functions. For this reason, it is necessary to develop a model for the new mobility and design an architecture involving the node ID/location ID separation technology that has recently been considered for introduction (for example [15]).

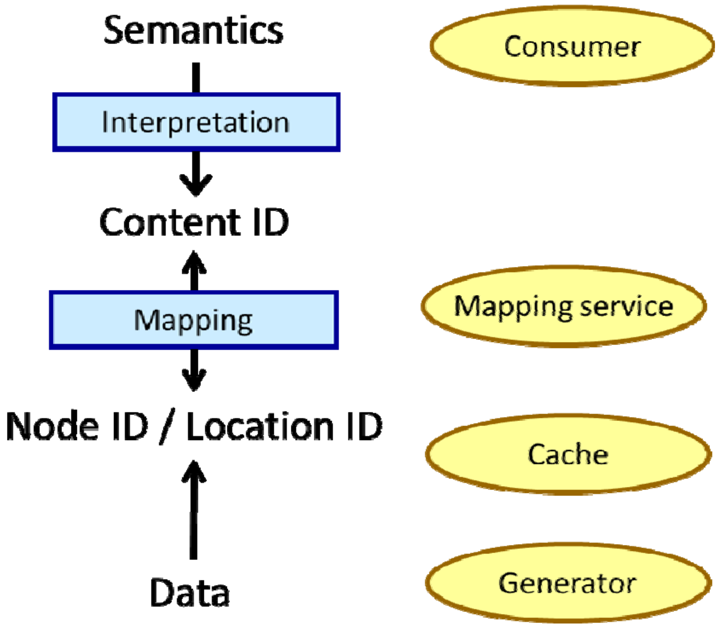

Fig. 8. Conversion from Semantics to ID and Mapping for Content Access

- Actuator driving technology based on its profiling and action
  In the future M2M communication, it is expected for networks or the services on networks to support people’s safe and good life by accurately processing the data dynamically generated and sent from a volume of the sensor devices and driving the actuators properly. That includes, for example, control of road signals and measures for air pollution based on the traffic information in the area, measures against irrigation and snow damage based on the information on temperature, humidity and rainfall in order to support the lifestyles of people. For its realization, the technologies to set up a profiling for a quick command and action scenarios in the service control function and to promptly provide the appropriate commands to in-network processing function, data storing function, replicated data function and other functions when necessary are required. If improved processing performance can be expected by synchronization of a volume of actuators, it is also important to create the action scenarios for that synchronization.

- Routing technology to utilize the cached data on network node
  From the view point of efficient search and transfer of contents distributed in a network, a design for routing to utilize the cached data on network node with the following enabling technologies is important.

1. Information-stored high-reliability routing technology (for example [16]): information is cached in a network node or replicated data storing function when no access to consumers who finally receive the information, data storing function or replicated data storing function is confirmed or when the middle path is congested. It is necessary to set up routing to quantify the reachability to destinations with the probability based on the history and then to transfer the information to the node with large probability.
2. Cache creation and guidance technologies for in-network content (for example [17]): When content is downloaded by consumers, execute processing to leave their footprints information linked with the content ID of a router on the path, set up a cache with the growing footprints and guide the content request hit to the footprints content to the cache.
3. Information-oriented routing technology (for example [7][8][9]): In the current Internet, users obtain the content by acquiring a location ID with a help of search engines. In order to solve this without using search engines, it is necessary to provide data ID/content ID for the replicated data or content in the network and execute routing with using it. For its realization, such enabling technologies, which can route data by data ID/content ID itself and acquire the content from the cache in a node when requesting content delivery to the service control function that can obtain the mapping information of the location ID of data ID/content ID and node cache, are required.

- Data allocation and caching

In the deployment of content data for network design, both (i) data provision phase and (ii) data acquisition phase need to be considered from the viewpoint of calculating the amount of traffic and power consumption.

(i) Data provision phase

A phase from after information is generated and saved in the specific content server until it is provided for in-network cache and storage functions.

(ii) Data acquisition phase

A phase where the information is completely provided for the cache and storage functions and access from each terminal to the information can be executed.

In terms of layout of the in-network cache and storage functions, an optimized design with estimation of the traffic and the content deployment amounts as well as consideration for cost for each function layout will be made. For the layout of the cash function (or storage function), the following two cases will be simulated (Fig. 9).

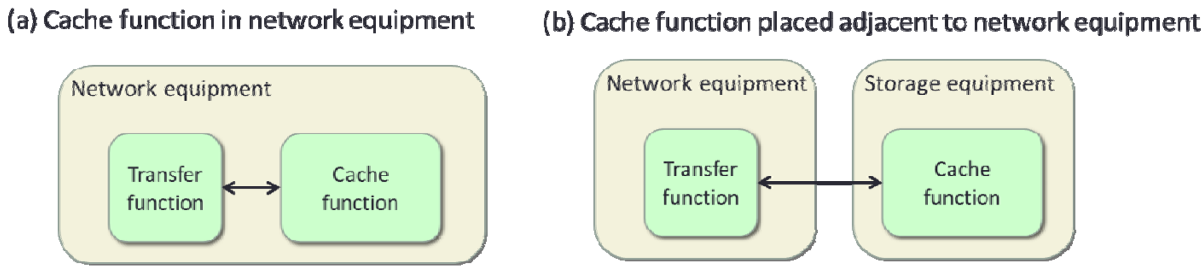

Fig. 9. Data Allocation and Caching

(a) Cache function in network equipment

Deployment of cache function in network equipment is simulated. This case enables high-speed access to the cached data and low power consumption. On the other hand, as there is a limitation in capacity of the cached data, it is necessary to arrange a layout in the appropriate network equipment, which takes into account a decent capacity of cache function by estimation of the content distribution amount.

(b) Cache function placed adjacent to network equipment

Deployment of cache function being placed adjacent to network equipment is simulated. This case enables selection of the general-purpose storage function and layout of relatively large volume of cache capacity at low cost. On the other hand, in terms of low power consumption, it is necessary to arrange a layout that takes into account a decent cache capacity using storage equipment with the measures for low power consumption by estimation of the content distribution amount.

- Traffic smoothing technology with cache of network nodes
  In the current network, for example, the content delivery from Web server or content server is executed by requests from users as client. When much of other traffic is distributed on the content delivery route, there will be a bottleneck line which causes a decrease in data transmission speed (throughput) in response to the data passing volume at the bottleneck. One measure to prevent the decrease of the throughput is to increase the capacity of the bottleneck lines. However, an increase of the line capacity allows a response at peak traffic, but it will result in an increase in power consumption due to the high-speed signals to be sent and received or the address search and exchange process of packets at high speed. Moreover, as the equivalent line speed is required to be provided also at off-peak traffic, the line cost and power consumption remain high, and therefore an increase in network operating cost cannot be avoided. For the purpose of temporal storage of data distributed in the network router or around the router, a cache function (replicated data storage function) need to be set. With a bottleneck link, it is possible to store data in the cache before the middle of the route and re-transfer data when the link load goes down. Or with the content distribution to multiple caches and with the request from users for data transfer for the corresponding server, that server provides an instruction on the cached data distribution to a cache with less network congestion. Such an effective cache layout and an efficient use technology of the cached data enable traffic smoothing at its peak. As a result, they can prevent the overloaded line capacity by network operator, contribute to the reduction in operation cost and reduce wasted power consumption.

- Multihome-based route selection technology in data transfer
  In the current network, it is generally difficult for a host to switch a communication interface, i.e., selection of a data transfer route, when keeping the communication with a correspondent for the host. On the hand, there are various proposals to make it happen in response to the recent diversification of access network and the popularization of a multihomed host [18][19]. For example in [18], considering a host ID as an information address, continuing information transfer is possible for a communication even when a location ID given to a host changes time-by-time. This technology has a high affinity for the new architecture with “dynamic change possible in host location ID with consideration information as address ”, and it is expected to examine an optimized structure based on the new architecture.
  It is also expected that the multihome-based routing technology in data transfer has a congestion avoidance effect on mobile access networks which is known as a big issue in the recent mobile data network. With the rapid spread of smartphones, au (KDDI) says for example that the number of its holders exceeds the one of the conventional mobile phone in 2012 [20]. Furthermore, it is said that the traffic volume for incoming and outgoing calls by smartphones will be 20-30 times more of the one with the conventional terminals [21], and due to this, the mobile traffic volume being dealt with by communication carriers is expected to increase explosively, say over 50 times more in 3 years from 2006 in the case of AT&T [22] (Fig. 10). In order to hold the exploding traffic, it is required not only to migrate it to mobile data network with higher system-frequency-usage efficiency but also to make active use of the WiFi lines with superior usage efficiency or the fixed Internet lines without frequency resource constraint instead of 3G lines. With these backgrounds, it is important to develop the technology to select appropriate access networks in data transfer.

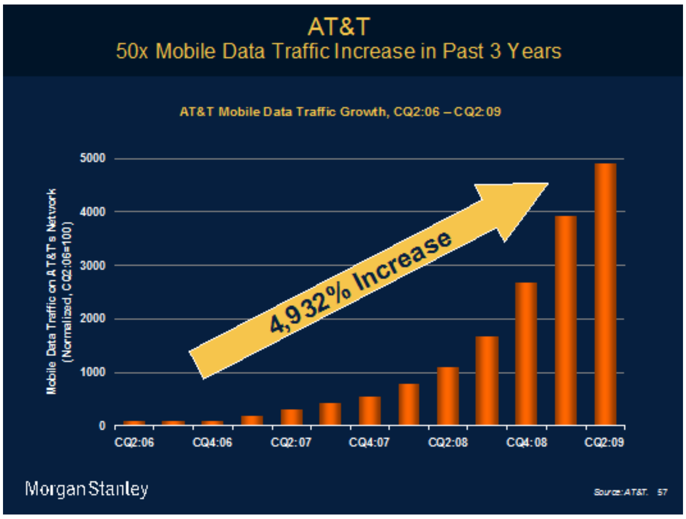

Fig. 10. Forecast Mobile Data by AT&T

- Power-saving data transfer technology
  The current Internet does end-to-end communication in terms of IP datagram (packet) in network layer. At a switching point in the network, a router placed at the switching point verifies the IP address embedded in the header of packet with a routing table in the router (routing table search) and transfers packets to the appropriate output line. Currently, routing table in the Internet core router is created by BGP (Border Gateway Protocol) and its entry reaches 400,000 [23]. In many core routers, although connection to other networks is made through the optical fiber, the search of routing table is conducted electronically with a large-scale TCAM (Ternary Content Addressable/Associative Memory) by converting optical signal to electrical signal. Searching by packet and verifying IP address by the whole memory consume a large amount of power. There is also a report that 42% of power consumption in a router is used by line cards with interfaces to external devices and 32% of it by LSI for searching [24]. There are four methods considered as follows in order to reduce the power consumption for packet transfer. All those are the infrastructure-building technologies that are applicable not only to the dynamic information diffusive network but the general network. Especially the third and fourth ones are expected to be applied to the routing with the active utilization of identifiers described in this section.
  The first method is cut-through for packet switching by utilizing optical path and traffic engineering [25]. This sets an optical path in the two points in which a large volume of data flow is made, omits the packet switching generated in the middle of the system and can bypass opto-electrical conversion and the processing for the routing table search by packet. This method is only applicable in a single network management area (single domain) but cannot be used in the area where BGP (Boarder Gateway Protocol) is applied.
  The second is introduction of optical technology in packet switching [26]. Minimizing the exchange of optical signal to electrical signal (for example, only the parts corresponding to a header in Reference [26]) realizes power saving. Utilizing the broadband performance of the optical signal and minimizing the header processing could also realize further power saving of the address processing itself as well.
  The third is regarding system and device for the structure for packet address search, establishment of a new address search and reduction in power consumption are conducted by the use of multiple small TCAMs (Ternary Content Addressable Memories) instead of using regular size one or by the use of less-power consumed memory such as SRAM (Static Random Access Memory) or DRAM (Dynamic Random Access Memory) instead of TCAM for the address search [27][28].
  The fourth is to make the routing table smaller. For example, allocating a locator to each network or router interface and terminal in accordance to hierarchical address structure that is recognized as provider aggregation can reduce a size of the routing table [29]. There is also an evaluation that the size re-

duction in routing table could be possible by changing only network locators of stub networks (i.e., networks only have upstream networks for transit) to the hierarchical ones, not changing locators of all the Internet service providers [30]. Moreover, an ID/locator separation structure, regardless of an overlay-type like LISP (Locator/ID Separated Protocol) [31] or a host-ID-based structure [15], can also reduce the entries of the routing table due to separation of routing in the edge and core network.

- Network management
  The current network operation and management needs not only to monitor the operational status of the each network node equipment such as a router or a server but also to monitor the operational status (1) as the whole network and (2) as a service, which are both cross-multiple-nodes. Examples of (1) include the route monitor for the Internet and internal networks [32]. Meanwhile, (2) includes the monitoring of reachability and quality for an end-to-end communication between hosts [33] and the flow-based traffic [34]. However, there will be an attention required that these are realized on the premise of the current network architecture “communicate with the host as destination”. The new network architecture as described earlier specifies the distributed information itself (such as data ID and content ID) as the address, performs communication by converting this to the host address (such as node ID and location ID) or executes routing based on a data ID or a content ID. In terms of the examples of (1) and (2), therefore, it is necessary to review the framework of the current network operation and management significantly as for instance the route monitor for reachability and quality between a host and information, or the monitor that is conscious of an intermediate node with a function for storing replicated data or for in-network processing is required.

- Authentication infrastructure
  Authentication and privacy protection technologies are required for registration and deletion of the 100 billion of sensor and actuator devices being connected to the network, location information updates for a billion of the moving mobile terminals and holding of the super large amount of information and contents. In the utilization form of the dynamic information-diffusive network that dynamically generates information and then sends it out to the network, it is necessary to build the authentication and trustable infrastructures [35] to manage the trustability of the network without sacrificing its performance, while connecting on to the network and off of it by a lot of devices and terminals as needed. In addition, a new function which accesses to the contents not by terminals or devices but by attribute authentication of data ID, content ID or service ID is also required. Or, light cryptographic protocols that are executable with low functionality device would be needed.

6. Architecture Realization Framework

6.1 Architecture Realization Framework for Dynamic Information Diffusive Network

This section describes an architecture framework for a series of the information flow from a phase of generating information (data) by mobile terminals or sensors up to the phase of acquiring information (contents, etc.) by consumers who are also users in the dynamic information diffusive network. The architecture functions include service control, mapping service, data storage, replicated data storage and in-network processing, and the architecture framework for signals and information exchange that are generated among these functions, information generators or consumers is described in this section. Each of these functions consists of multiple individuals and information needs to be exchanged among those individuals, for example among multiple mapping service functions in the case of mapping service. The information exchange inside the functions, however, will not be mentioned in here.

Following are the definitions of generator, consumer and each function:

- Generator
  Generator is an object to generate and send out a data and includes a mobile object, fixed terminal and sensor which have a transmitting function to a network. In the case that a sensor does not have a communication function, if the first owner receiving data from the sensor has that feature, then the first owner is considered as a generator.
- Consumer
  Consumer is an object to acquire information at the end regardless of the request for information receiving.
- Service control function
  Service control function executes the various following controls on the network services. For consumers, this function receives a request for the data receiving unambiguously and makes an appropriate action for in-network function, and it offers the information needed for data receiving to consumers. This function is also responsible for information distribution control in a network. User profile, routing and caching policy are implemented in the function.
- Mapping service function
  Mapping service function is to make the connections between information and a node storing the information, location and service utilizing the information, between an object and its location, between a consumer and a service that the consumer utilizes.
- Data storage function
  Data storage function is an in-network function to store the information generated. With the in-network processing indicated below, original information including newly generated one is stored.
- Replicated data storage function
  Replicated data storage function is an in-network function to temporarily store information including the one replicated from the data storing function.
- In-network processing function
  In-network processing function is to execute processing which converts information to a different form.

Data is transferred among these functions by exchanging messages including identifiers as defined below. The category can be user ID, data or content ID, service ID, node ID and location ID, which is defined in the Reference [36]. Furthermore, user ID can be divided into generator ID and consumer ID. The details of each ID are defined as follows:

A) User ID
   A user ID is assigned to a user to uniquely identify the user in the network. User IDs are used to search, authenticate, authorize and bill the user for a service.

B) Generator ID
   A generator ID is one of the user IDs and assigned to a user that sends a data.

C) Consumer ID
   Consumer ID is one of the user IDs and assigned to a user that receives a data.

D) Data/Content ID
   A data/content ID is assigned to a data or content to uniquely identify it independent of its location or owner. The use of data/content IDs would be helpful to create a new network architecture based on an information-centric paradigm and to enhance data security in the information node processing or the content delivery. This feature is also helpful for content mobility and caching.

E) Service ID

Service IDs can further be divided into two subcategories: content service ID and network service ID. A content service ID specifies an application service and associates with service related attributes, such as the security keys, sequence numbers, and states. The content service IDs would be mainly used by servers and client nodes to identify the services. A network service ID will specify a data forwarding service provided by the network nodes. It may specify a logically isolated network partition (LINP) in network virtualization [37], a virtual local area network (VLAN), or a particular protocol used for handling data packets (e.g. forwarding, queuing, QoS support) in the network.

F) Node ID
A node ID is assigned to a physical or virtual device to uniquely identify it independent of its location in the network. The node ID would be used for access control of mobile nodes, trust establishment between nodes, and to identify communication sessions existing between the nodes.

G) Location ID
A location ID or locator is assigned to a device or node to locate it in the network topology. The locator is used by the routing infrastructure to locate the node uniquely in the network topology. Locator formats are dependent on the network layer protocols or routing protocols which are used to locate the destination node and forward data towards it through the network.

Function-to-function signals and information flow on information upload and download, information distribution, information registration and an actuator drive are described below. Fig.11 shows the function-to-function signals and information flow in all those processing. Solid lines indicate the information flow and dashed lines indicate the control signal flow. The direction of arrows follows the flow of information for the information flow. As for the signal flow, a starting point is the origin of each flow. Two-way communication is conducted both in the information flow such as ACK in TCP and in the signal flow such as a response signal for a request, but that part is omitted in here. With a case that both sides become the upstream of the information flow or the origins of the control, a two-way arrow is used. The same can be applied to other figures, Fig.12 through Fig.18.

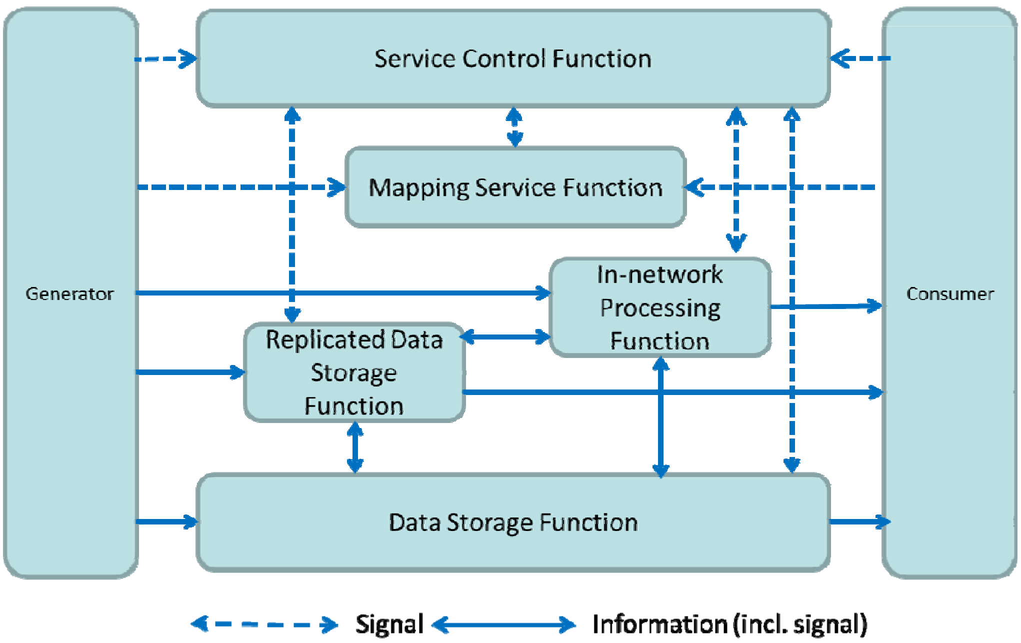

Fig. 11. Architecture Realization Framework (Total Image)

<u>Information Upload</u>
In the information upload, information flows are designed under the assumption of the following 5 cases. The solid lines in Fig.12 indicate the information flows among functions. The blue letters mean the signals or information considering an in-network function as an origin, while the red ones mean the signals or information considering generator/consumer as an origin.

(1) Generator → Data storage function → Replicated data storage function
Send an information upload from a generator to a data storage function and then also send it to a replicated data storage function.

(2) Generator → Replicated data storage function → Data storage function

Send an information upload from a generator to a replicated data storage function and then also send it to a data storage function.

(3) Generator → In-network processing function → Data storage function
When uploading information, conduct data processing treatment in an in-network processing function and then send the processed data to a data storage function.

(4) Generator → In-network processing function → Replicated data storage function
When uploading information, conduct data processing treatment in an in-network processing function and then send the processed data to a replicated data storage function.

(5) Generator → In-network processing function → Replicated data storage function → Data storage function
When uploading information, conduct data processing treatment in an in-network processing function and then send the processed data to a replicated data storage function. Afterwards also send it from a replicated data storage function to a data storage function.

In any of these cases, when a generator uploads data, the signal exchange and control (Fig.12) required among the following functions A)-H) need to be conducted.

A) Generator → Mapping service function
Name resolution for service control function and for functions for replicated data storage, data storage and in-network processing where data is uploaded.

B) Generator → Service control function
Acquisition of service ID. Request for information upload.

C) Service control function → Mapping service function
Name resolution for a necessary function for the upload request from a generator. Registration of the map information generated from an ID that was delivered to the service control function.

D) Service control function → Replicated data storage function
A command to transfer the information of (2)(5) for the upload request from a generator.

E) Service control function → Data storage function
A command to transfer the information of (1) for the upload request from a generator.

F) Service control function → In-network processing function
A command to process (3)(4)(5) or transfer these results for the upload request from a generator.

G) Replicated data storage function → Service control function
Transfer an information ID uploaded from a generator.

H) Data storage function → Service control function
Transfer an information ID uploaded from a generator.

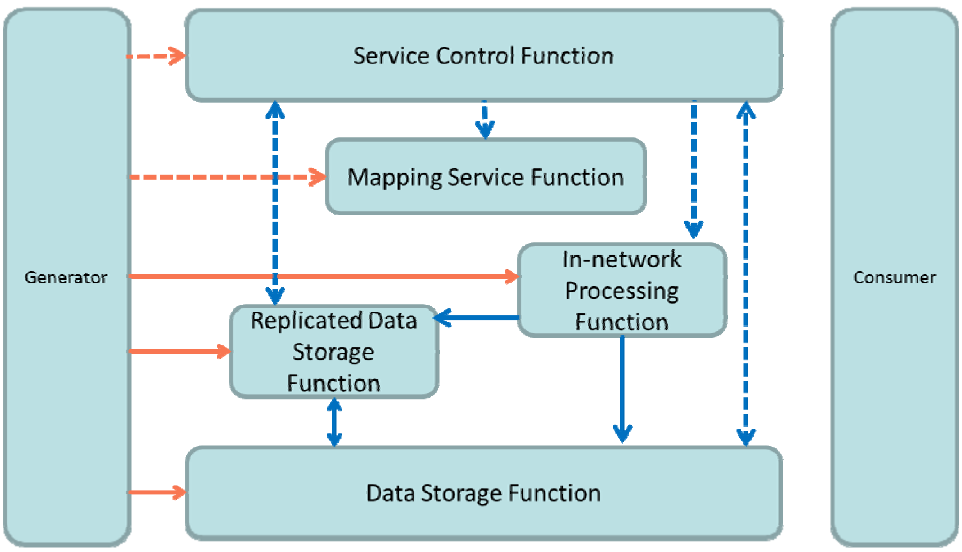

Fig. 12. Signals of Data Upload and Its Dataflow

Information Download

In the information download, information flows are designed under the assumption of the following 9 cases. The solid lines in Fig.13 indicate the information flow among functions.

(6) Replicated storage function → Consumer
A consumer receives the information already sent to a replicated data storage function from there.
(7) Data storage function → Consumer
A consumer receives the information that is not yet sent to a replicated data storage function from a data storage function.
(8) Data storage function → Replicated data storage function→ Consumer
A consumer receives the information, which is not yet sent to a replicated data storage function, from the replicated data storage function. In the middle of data receiving by a consumer, the data is copied from a data storage function to the replicated data storage function.
(9) Replicated data storage function → In-network processing function → Replicated data storage function → Consumer
A consumer receives the processed information, which was already in a replicated data storage function before being processed in an in-network processing function, from the replicated data storage function.
(10) Replicated data storage function → In-network processing function → Consumer
A consumer receives the processed information, which was already in a replicated data storage function before being processed in an in-network processing function, directly from the in-network processing function.
(11) Data storage function → In-network processing function → Replicated data storage function → Consumer
The information, which was stored in a data storage function, is processed in an in-network function. The processed information is stored in a replicated data storage function first and then transferred to a consumer from there.
(12) Data storage function → In-network processing function → Consumer
The information, which was stored in a data storage function, is processed in an in-network function. Then a consumer receives the processed information from there.
(13) Data storage function → Replicated data storage function → In-network processing function → Replicated data storage function → Consumer
The information, which was stored in a data storage function, is replicated to a replicated data storage function, and it is processed in an in-network function. The processed information is then stored in a replicated data storage function first and transferred to a consumer from there.
(14) Data storage function → → Replicated data storage function → In-network processing function → Consumer
The information, which was stored in a data storage function, is replicated to a replicated data storage function, and it is processed in an in-network function. A consumer then directly receives the processed information from there.

In any of these cases, when a consumer downloads data, the signal exchange and control (Fig.13) required among the following functions A)-F) need to be conducted.
A) Consumer → Mapping service function
Name resolution for service control function and for a function where data is downloaded.
B) Consumer → Service control function
Acquisition of service ID. Request for information download.
C) Service control function → Mapping service function
Name resolution for a necessary function for the download request from a consumer.
D) Service control function → Replicated data storage function
A command to transfer the information of (6)(8)(9)(10)(11)(13)(14) for the download request from a consumer.
E) Service control function → Data storage function
A command to transfer the information of (7)(8)(11)(12)(13)(14) for the download request from a consumer.
F) Service control function → In-network processing function
A command to process (9)-(14) or transfer these results for the download request from a consumer.

How to utilize these depends on the service form. For instance, in a model that a consumer as a starting point generates all the requests, A) conducts the name resolution for service control function and a function where data is downloaded. After that, the consumer receives the information from a replicated data storage or data storage function. For a case that the service control function handles the consumer's request, A) only does the name resolution for service control function, and the service control function takes care of all requests for the downloaded destination. Afterwards the consumer receives the information from a replicated data storage or data storage function.

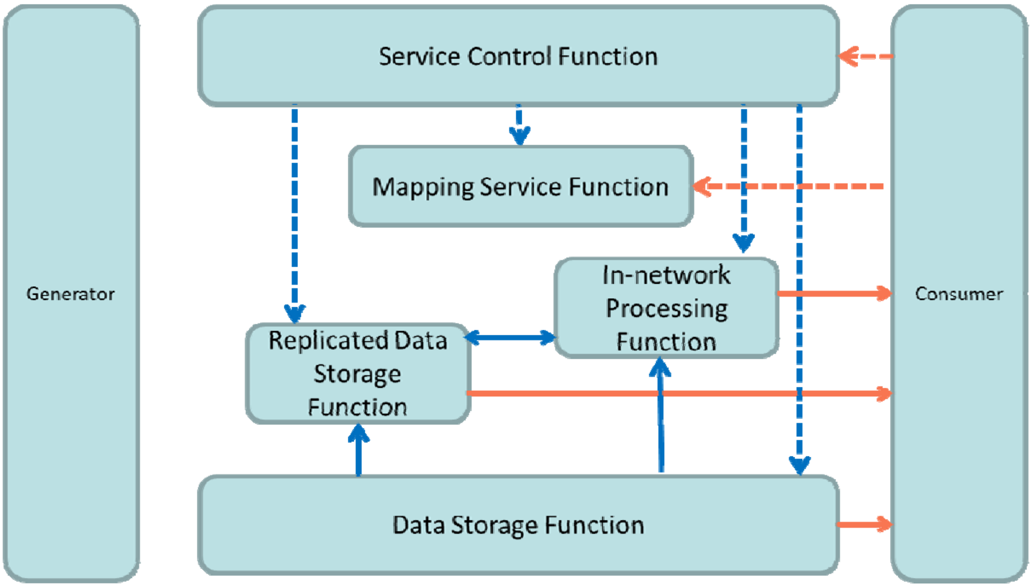

Fig. 13. Signals of Data Download and Its Dataflow

Information Distribution
In the information distribution, information flows are designed under the assumption of the following 4 cases. The solid lines in Fig.14 indicate the information flow among functions.

(15) (Replication of information) Data storage function → Replicated data storage function
The information stored in a data storage function is sent to a replicated data storage function, and the information is replicated by storing it into the replicated data storage function.

(16) (Data processing) Data storage function or replicated data storage function → In-network processing function → Data storage function
The information stored either/both in a data storage function or/and in a replicated data storage function is sent to an in-network processing function, and the information is processed in the in-network processing function. Then the processed information is stored in a data storage function.

(17) (Data processing) Data storage function or replicated data storage function → In-network processing function → Replicated data storage function
The information stored either/both in a data storage function or/and in a replicated data storage function is sent to an in-network processing function, and the information is processed in the in-network processing function. Then the processed information is stored in a replicated data storage function.

(18) (Data deletion) Service control function → Mapping service function and replicated data storage function
Delete the information in a replicated data storage function (and at the same time delete the information registered to the mapping service function.)

In any of these cases, when information is distributed, the signal exchange and control (Fig.14) required among the following functions A)-D).

A) Service control function → Replicated data storage function
Replication of information. (16)(17) Placement of in-network processing. (18) Data deletion.

B) Service control function → Data storage function
(15) Replication of information. (16)(17) Placement of in-network processing. (18) Data deletion.

C) Service control function → In-network processing function
(16)(17) Execution of in-network processing. Notification of the load status for processing. Notification of the information storage volume for replicated data storage function.

D) Service control function → Mapping service function
Name resolution for a function needed for information distribution. Registration of the mapping information generated from the ID that is delivered to the service control function by (15)(16)(17). (18) Deletion of the registered information.

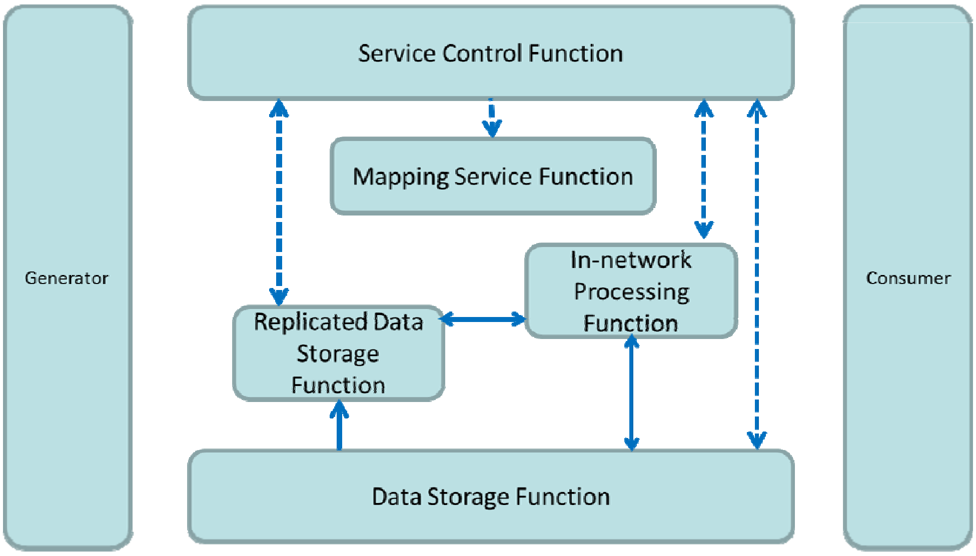

Fig. 14. Signals of Data Allocation and Framework for Data Transfer

Registration of Terminal and Information

In the registration of terminals and information, information flows are designed under assumption of the following 6 cases (Fig.15).

(19) Generator → Service control function → Mapping service function
Send the registered information of terminal or information from a generator to a service control function and then also send it to a mapping service function.

(20) Generator → Mapping service function → Service control function
Send the registered information of terminal or information from a generator to a mapping service function and then also send it to a service control function.

(21) Generator → Service control function, Generator → Mapping service function
Send the registered information of terminal or information from a generator to a service control function and mapping service function.

(22) Consumer → Service control function → Mapping service function
Send the registered information of terminal from a consumer to a service control function and then also send it to a mapping service function.

(23) Consumer → Mapping service function → Service control function
Send the registered information of terminal from a consumer to a mapping service function and then also send it to a service control function.

(24) Consumer → Service control function, Consumer → Mapping service function
Send the registered information of terminal from a consumer to a service control function and to a mapping service function.

When registering information, appropriate control needs to be executed by using a generator ID, consumer ID, service ID, data ID, node ID and location ID.

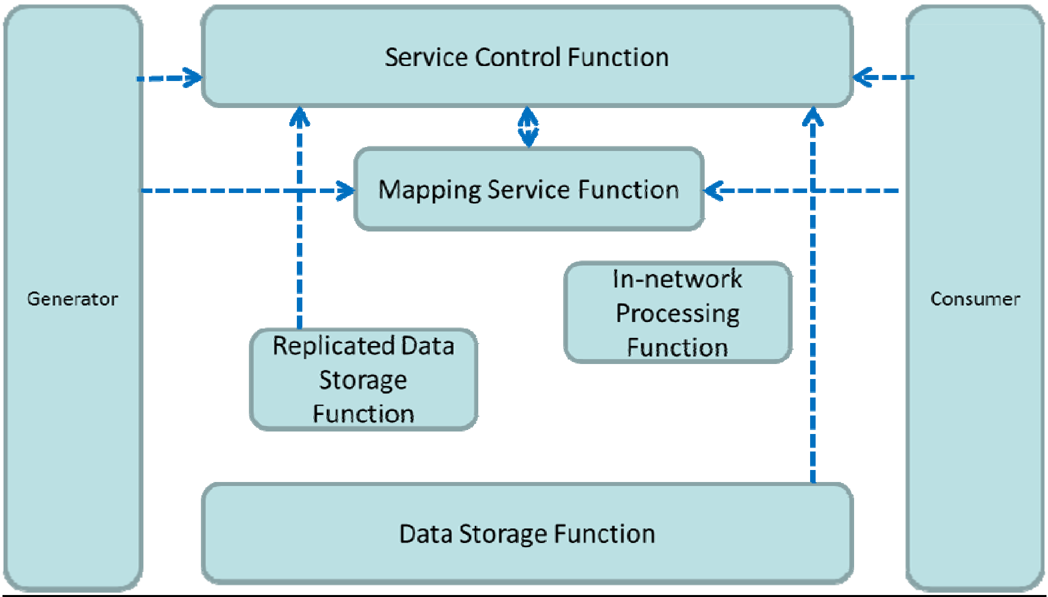

Fig. 15. Framework for Signal Transfer of Information and Equipment Registration

<u>Actuator Drive</u>

The following 3 cases describe the information flow for offering a service to control and drive an actuator. The solid lines in Fig.16 indicate the information flow among functions. Also, it is based on the premise that the service control function has an execution scenario to drive the actuator.

(25) Replicated data storage function → Consumer

Replicated data storage function sends a data with the description of execution details of an actuator to a consumer (actuator) according to the demand from a service control function. The consumer (actuator) executes what is described in the data.

(26) Data storage function → Consumer

Data storage function sends a data with the description of execution details of an actuator to a consumer (actuator) according to the demand from a service control function. The consumer (actuator) executes what is described in the data.

(27) Data storage function or replicated data storage function → In-network processing function → Consumer

Data storage function or replicated data storage function sends a data to an in-network processing function according to the demand from a service control function. The in-network processing function processes the received data, converts it to the execution details of an actuator and then sends it to a consumer (actuator) according to the demand from a service control function. The consumer (actuator) executes what is described in the data.

In any of these cases, the signal exchange and control (Fig.16) required among the following functions A)-D).

A) Service control function → Mapping service function

Name resolution for a necessary function for processing (25)(26)(27).

B) Service control function → Replicated data storage function

A command to take out the execution details of the actuator for processing (25)(27).

C) Service control function → Data storage function

A command to take out the execution details of the actuator for processing (26)(27).

D) Service control function → In-network processing function

A command to process the delivered data for processing (27) and to send the processed execution details to a consumer.

Also, this model enables to describe the information distribution function not only to the actuator drive but to the subscriber (consumer) in Publish/Subscribe-based communication.

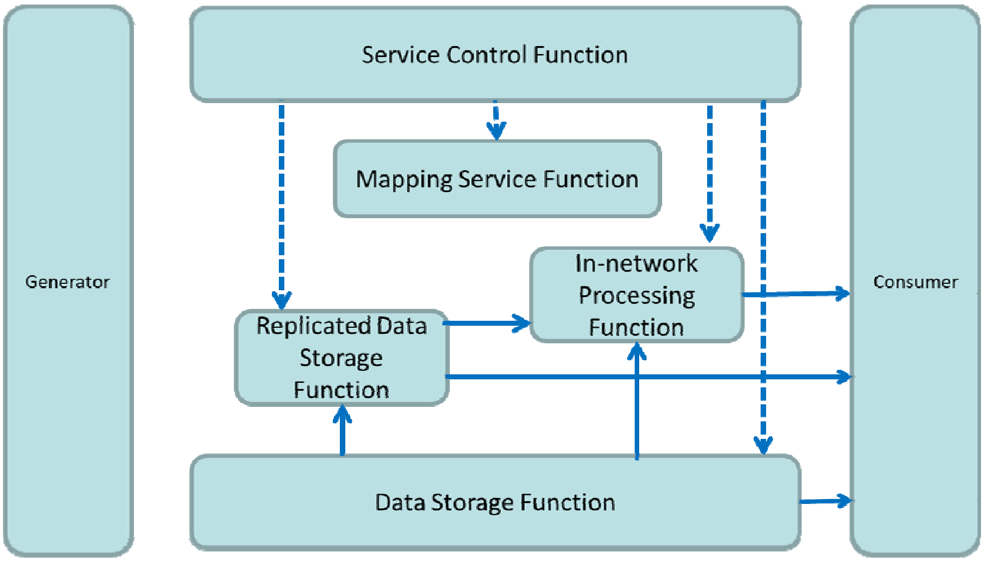

Fig. 16. Signals of Actuator Driving and Framework for Information Transfer

6. 2 Framework Comparison with Existing Network and Information Distribution Services

<u>Internet</u>

The major communication of the Internet is server-client communication including Web, e-mail, YouTube and file sharing. A generator with a data storage function builds a Web server and the integration of the generator and data storage function becomes a server. A consumer demands a content delivery for the server. A search engine becomes a service control function which acts as intermediary between consumer and server. In order to realize the service control function, a crawler lying in the backends of the search engine acquires the most updated data from the server. Mapping service in between these components is a DNS that converts names and locators or takes the names from the locators.

The major information flow is described as follows:

(1) Information download
Generator/data storage function → Consumer
A demand from consumer to generator/server creates information flow.

(2) Information search
Consumer → Search engine (service control function) → Consumer
This is sometimes executed before information download. Location information of the content is forwarded from a search engine.

(3) Information crawl
Generator/data storage function → search engine (service control function)
A demand from crawler (service control function) to generator/data storage function creates information flow. A conversion processing from a node ID (name) to a location ID and its reverse conversion processing is demanded for the mapping service as necessary.

(4) Server registration/deletion
Generator/data storage function → Mapping service function

Fig.17 indicates the information flow among functions. The flow of information and signals in the figure looks simple, however, in fact the service control function and data storage function are independent of each other and also independent services of the network providers.

Following are the points that the dynamic information diffusive network is different from the Internet:

- A system to separate a generator from data storage function and to collect information by the M2M communication is established.
- A system to make an easy access to the information by consumer with the establishment of a replicated data storage function and realize smoothing for data/content transfer is established.
- A system to create a new value from the information with in-network processing is established in the net-

work.

- Information distribution is promoted with the introduction of a new service control function,.
- A mapping service function with not only the mapping between names and location IDs but the one for various mapping is established.
- A service control function is established in the network instead of the search engine crawler being existing independent of the network providers.

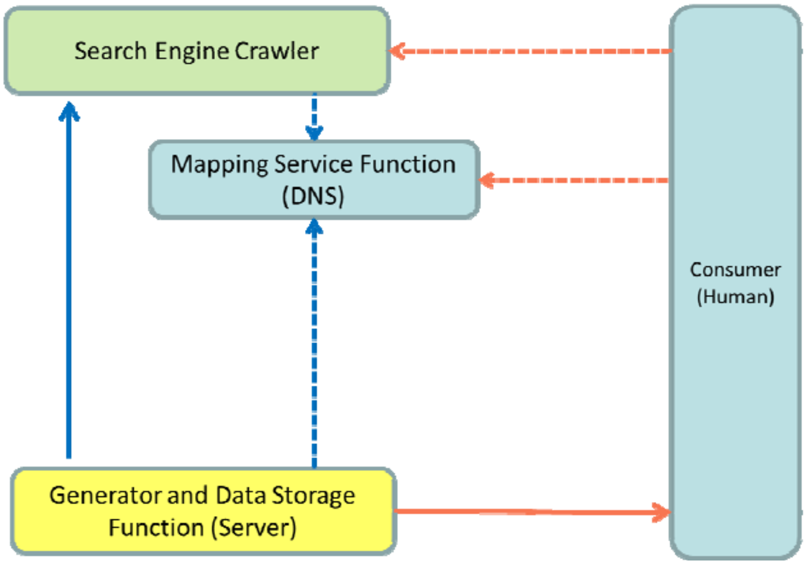

Fig. 17. Framework for Internet

<u>CDN (Contents Delivery Network)</u>

This is a service network which stores information in a data storage function or replicated data storage function in advance and once receiving a request for information distribution from the requestor (consumer), the network sifts out a location of the information and then transmits it to the requestor. The generation and processing of information are usually conducted in which is separated from the network and therefore, data storage function and generator are considered as a unit. There is no in-network processing function. In terms of the map server, a service control function as a service window for consumers in CDN specifies the appropriate server (data storage function or replicated storage function) depending on the consumer's condition, which realizes a low-stress content delivery. Specifying the closest server to a consumer with DNS is an example for the service control function. The major information flow is described as the following 3 cases:

(1) Data replication
Data storage function → replicated data storage function. An instruction from service control function to data storage function makes transferring information.

(2) Content delivery
Generator/data storage functions or replicated data storage function → Consumer. A demand from consumer to service control function and a response in the content location information to consumer makes transferring information.

(3) Server registration/deletion
Generator/data storage function → service control function (same applies to the registration/deletion of replicated data storage function).

Fig.18 indicates the information flow among functions. Functions including service control indicated here are independent of the one of the network providers. The complexity that the functions are actually deployed in the network to be serviced will be described in the following subsection.

Following are the points that the dynamic information diffusive network is different from CDN:

- A system to separate a generator from data storage function and to collect information by the M2M communication is established.
- A system to create a new value from the information with in-network processing is established in the network.
- Unlike a service control function existing independently from network service providers, information distri-

bution is promoted with the introduction of a new service control function in the network,

- A mapping service function with not only the mapping between names and location IDs but the one for various mapping is established.

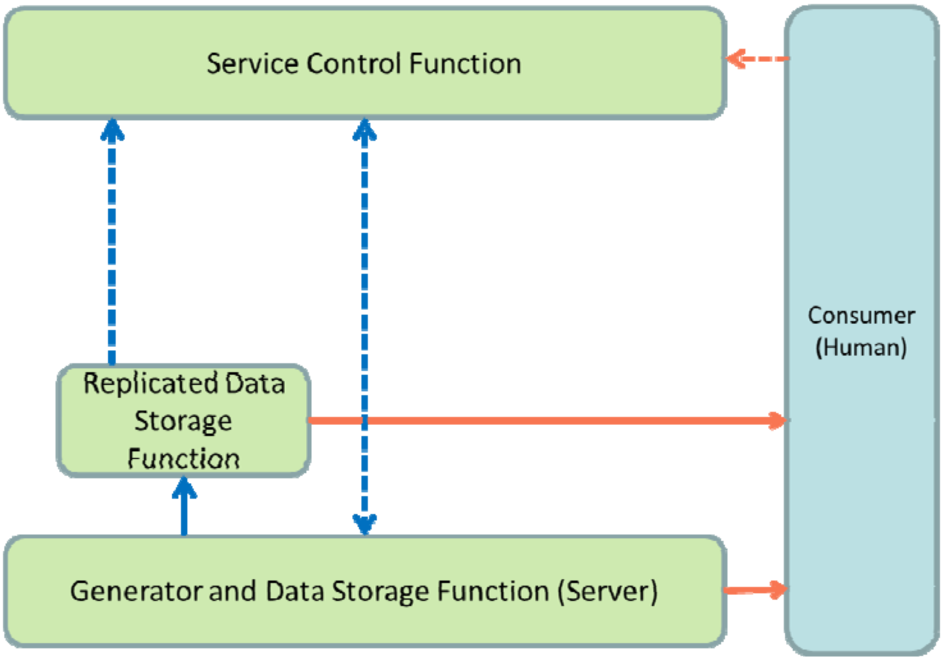

Fig. 18. Framework for CDN

6. 3 Examples of In-Network Usage of Each Function

Up until the previous section, the data and signal flows among functions as an architecture framework for the dynamic information diffusive network are summarized and the comparison in function of the Internet is made. As a premise of the differences in these functions, this subsection explains the layout examples that deploy each function described in the previous subsections to inside the network and specifies the functional edge for the dynamic information diffusive network.

Fig. 19 shows an example of the function layout for the case that an information search service and a content delivery service are provided over the Internet described in the previous subsection. There are multiple search engines for the service control functions existing in the Internet, and any of those is independent from the services by the network providers. As each crawler for information acquisition constantly obtains data from the web server (generator and data storage function) on the Internet in order to make up the data for search engines, this might cause a risk of much more traffic flow exceeding the volume of what the network providers assumed at their network design stage. There are several information search services like this, such services usually cause overloading of the network and also prevent consumers from selecting the best appropriate search engine.

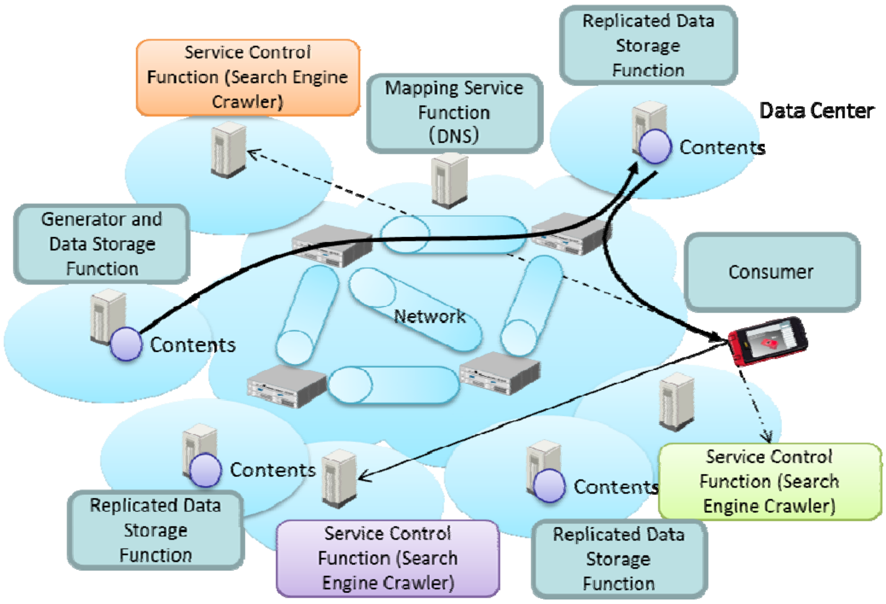

Fig. 19. Independently-provided Information Search Services and CDN from Network Infrastructure Providers

Fig. 20 shows an example of the function layout in the dynamic information diffusive network described in Subsection 6.1. In this case, as network service providers control the information distribution by themselves or so do content providers who are working with network service providers, stable information distribution with a decent amount of traffic is possible in time and power consumption for information transfer.

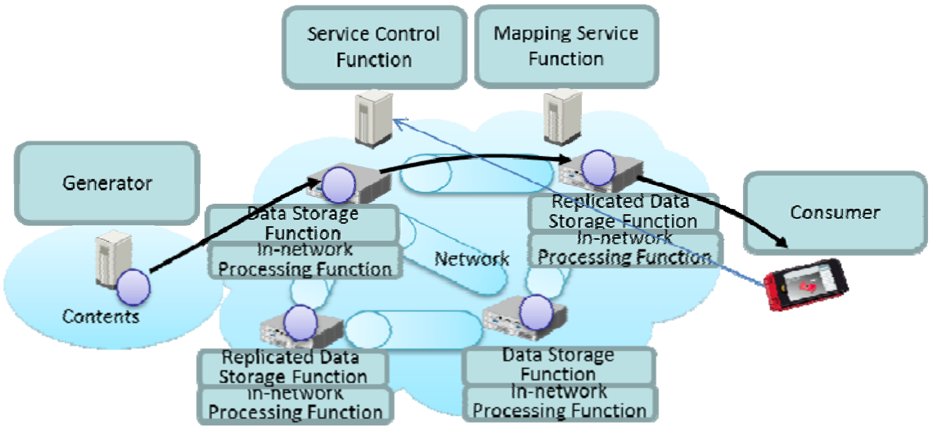

Fig. 20. Dynamic Information Diffusive Network

7 Specific Example of Network CAPEX Estimate

In this section, we estimate the amount of traffic flowing between storage devices under conscious of local generated-data for local consumption to figure out the bandwidth and power consumption necessary for establishment and operation of the network. The estimate will be contributed to a physical infrastructure design for a single network service or a virtualized network infrastructure design for multiple network service accommodation. Here we compare content delivery in dynamic information diffusive network with that in a CDN or that in an extended CDN which is also applied to upload data transfer. The CDN is supported as a network model where contents are maintained in a centralized way. The dynamic information diffusive network is a network model where contents are maintained in a distributed way. Each of them has a different business model in the type of data to be handled and what the network controls for and so on. The CDN treats the existing statically stored contents. On the other hand, the dynamic information diffusive network treats a wide range of information from the diversified data generated by humans and machines to value-added contents and takes into consideration the distributed contents management that is required in accordance with data diversification and its increase, data localization, and data mobility. This section develops a numerical model for deriving the total amount of traffic, consumed power, and node cache capacity in the dynamic information diffusive network and estimates their amounts. Comparing with CDN, the dynamic information diffusive network can reduce the required channel capacity and power consumption for operator view and reduce time for data access for user view. Here the dynamic information diffusive network is considered as a large-scale information distributed network by a single domain.

Fig. 21 shows a topology example of a dynamic information diffusive network. The network consists of core, metro, access, and end. Each core node in the core network consists of core routers (CR) and storage devices (St). The storage devices in the core nodes are used as cache. Contents are retrieved from the storage devices when the cache is hit. Similarly, each edge node in metro networks consists of edge node routers (ER) and storage devices. An edge node also has cache. Contents are retrieved from the storage devices when the cache is hit. Although notations in the figure are omitted due to readability, a core node, an edge node, and a user terminal are denoted as CN, EN, and UT, respectively. We assume that a metro network has 8 edge nodes. An access network has an optical line terminal (OLT) in a central office and optical network units (ONU) for subscriber side. Fixed terminals and mobile terminals are located in the end. The core nodes and the edge nodes have data storage functions and duplicated-data storage functions described in Section 6. (These nodes also have in-network processing functions and mapping service functions, and service control functions but these functions are not related to the estimates in this section). The fixed terminals and the mobile terminals are mapped into generators and/or consumers.

Hereafter, we estimate the total amount of traffic, the total power consumption, and total node cache capacity for two cases; one is that both generators and consumers are mobile terminals and the other is that both generators and consumer are fixed terminals.

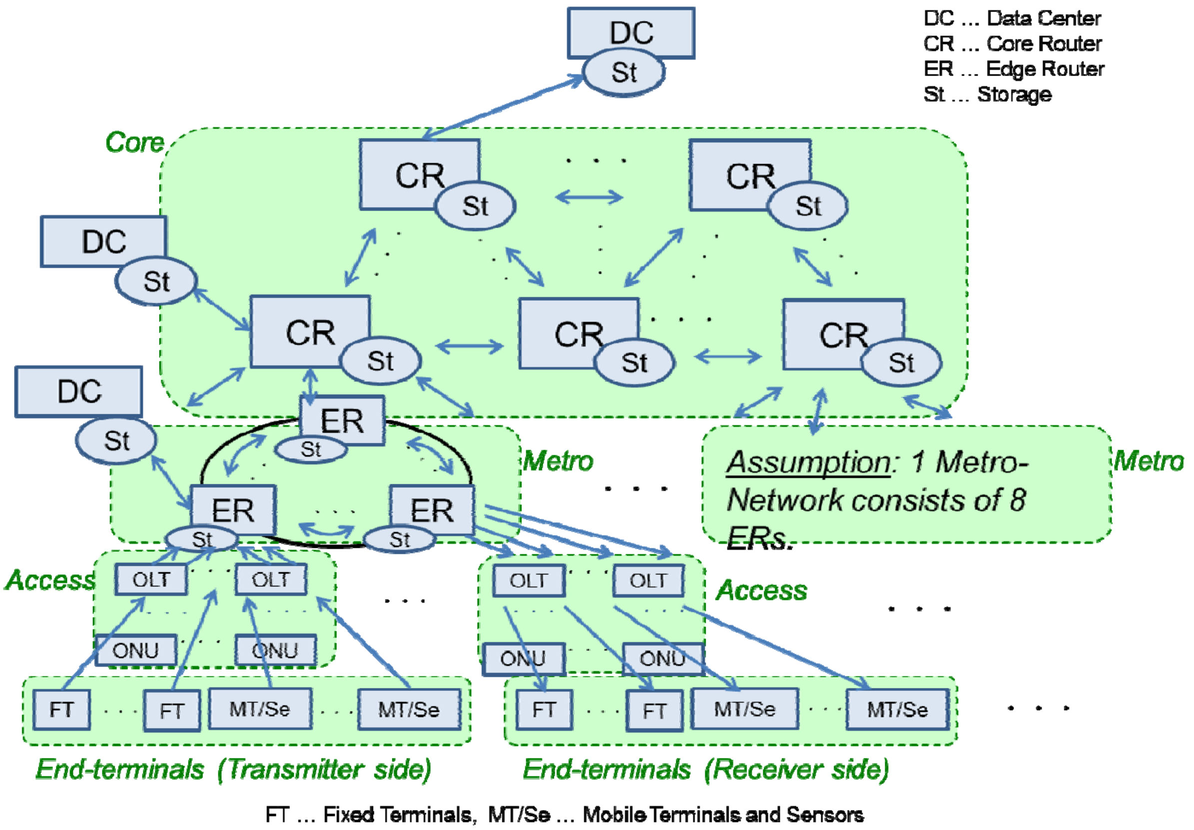

Fig. 21. Dynamic Information Diffusive Network Topology for Estimates

7.1 Numerical Calculation for Mobile Terminals

In this subsection, we develop a numerical model for estimating the amount of data distribution in a network where moving mobile terminals send and receive data and estimate the total amount of traffic, total power consumption, and total node cache capacity. For the development of a numerical model, considering its locality we assume a sequence that data is generated and sent to the network by a generator, then stored in the network, and finally received and consumed by a consumer. Each mobile terminal (a generator and a consumer) is capable of bi-directional communications but it can only send or receive a single data at a time. The way of communication in which data that has already been stored is copied to other nodes is out of scope of this model.

Fig. 22 shows the dataflow in a dynamic information diffusion network for the estimate. In uploading data to storage devices (data storage functions and replicated data storage functions in Section 6), data is stored in a storage device outside the network such as data center (hereafter an outside storage device of network) if data is not stored or cached in any edge node and any core node. Similarly, in downloading data from storage devices, data is retrieved from an outside storage device of network if data is not hit at any edge node and core node (in closed area).

Dataflow that the uploaded data from a generator is stored in the closest edge node and the data is transferred to a consumer from the edge node is divided into three cases: Case1, Case 2, and Case 3 shown in Fig. 23. This is a different approach form the existing CDN because the consumer does not obtain data from a core node or an outside storage device of network but it obtains data from the edge node. As both sending terminal (generator) and receiving terminal (consumer) are moving in this case, there might be a possibility that a mobile terminal may access to different edge nodes over time. (In Fig.23, each dataflow case is applicable to any of the Case 1, Case 2 or Case 3 even if a generator moves.) Case 1 is a case where uploaded data from a generator is stored in the closest edge node and the data is downloaded from the edge node by a consumer attached to the same edge node (see red lines in Fig. 22). This is local generated-data for local consumption. Case 2 is a case where uploaded data is stored in the closest edge node (say A) from a corresponding mobile terminal as generator and data is downloaded by a mobile terminal (as consumer) that are accommodated by one of other edge nodes in a metro network with the edge node A (see blue lines in Fig. 22). Case 3 is a case where uploaded data is stored in the closest edge node (say A) from a corresponding mobile terminal as generator and data is downloaded by a mobile terminal (as consumer) that is accommodated by one of edge nodes in a different metro networks with the edge node A (see green lines in Fig. 22). Namely, in case 3, data is distributed through a core network. Case 4 is a case where data generated at a mobile terminal is sent and uploaded to a core node. Since a receiving mobile terminal as consumer fails a desired data hit at the edge node cache, it searches core node cache and downloads the data stored in the core node. Case 5 is a case where no edge node and no core node stores data generated at a mobile terminal. In this case, data is stored in an outside storage device of network. A receiving mobile terminal as consumer searches data in an outside storage device of network and downloads the data stored in the storage device.

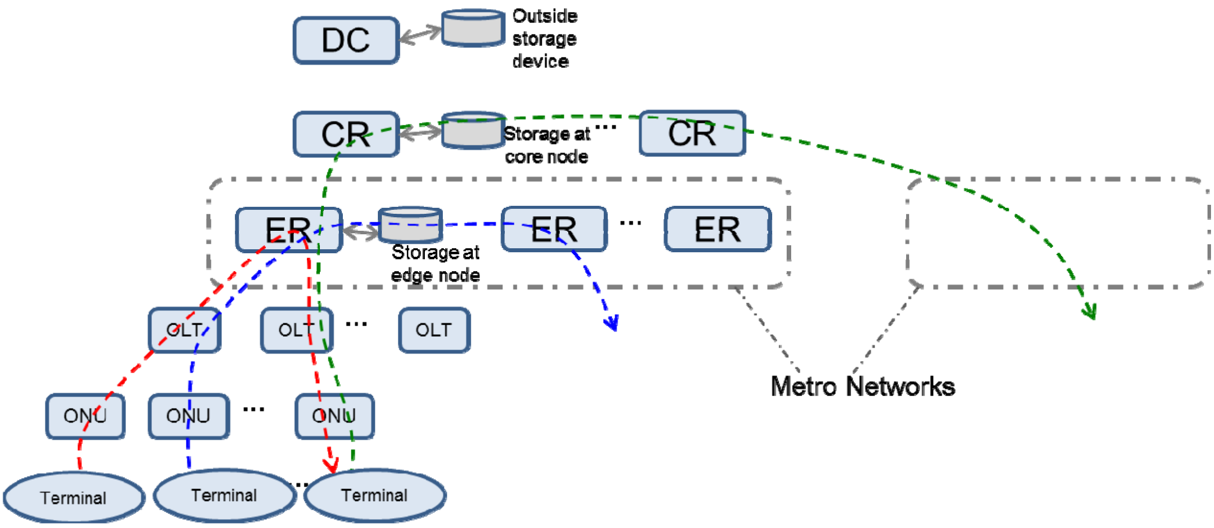

Fig. 22. Dataflow of Dynamic Information Diffusive Network in Mobile Terminal (Total)

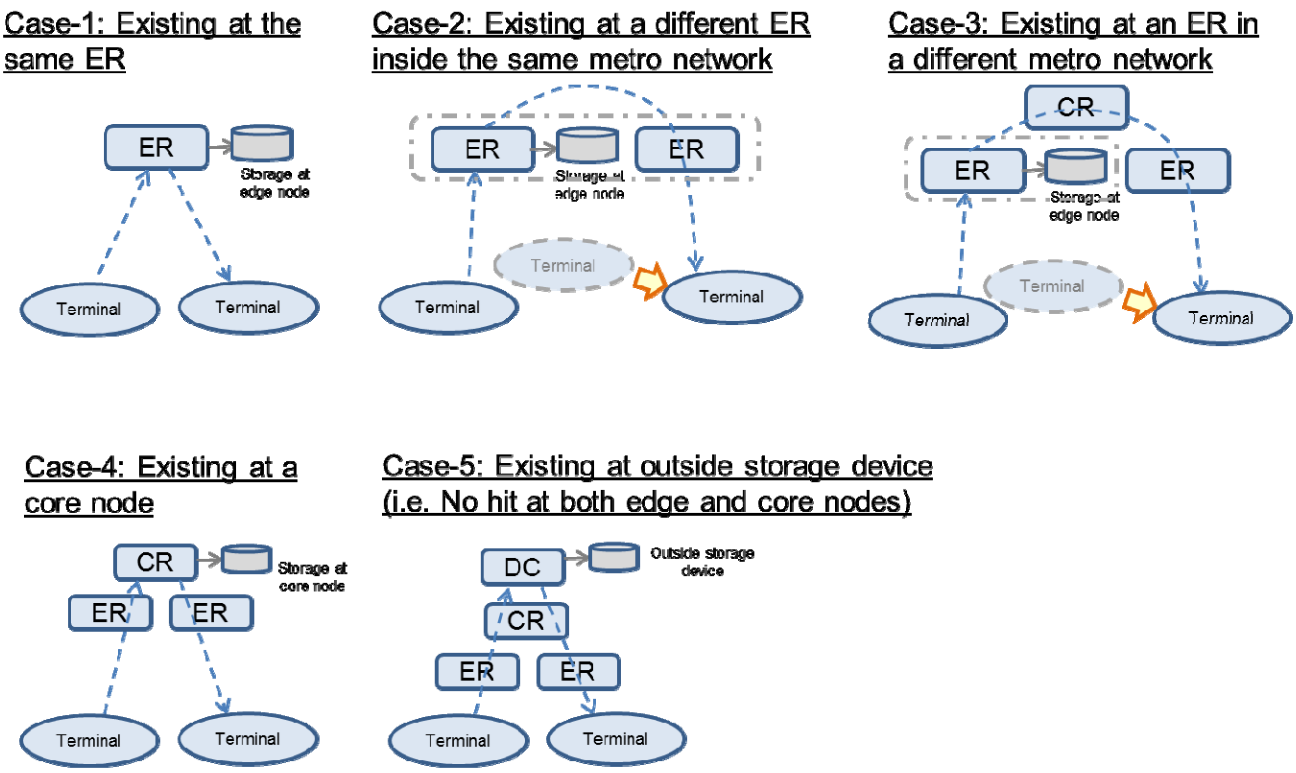

Fig. 23. Dataflow of Dynamic Information Diffusive Network in Mobile Terminal (By Hit)

Preconditions for Various Calculations

M2M wireless communication devices are categorized into fixed wireless devices such as fixed sensors, safety cameras and actuator devices and also mobile devices such as cellular phones and vehicle communication terminals. According to the design goal described in Section 4, we assume that an operator accommodates 100 billion (10^{11}) fixed wireless devices and 1 billion (10^{9}) mobile devices (10 devices for each resident). The 1 billion is set as X. With a fact that there are 363 municipalities (cities, special wards, towns, and villages) with the population of more than 80 thousands existing across the country, we assume 363 metro networks each of which is deployed in the corresponding municipalities, A metro network has 8 edge networks. Therefore, the total number of edge nodes N is 2,904 (8*363). Then, the average number of mobile terminals for each edge node is 344,352. Assuming that each prefecture has 2 core nodes in average, the total number of core nodes M is 100. Thus, a core node could accommodate 3.63 metro networks in average. Data is continuously uploaded at a rate of c_U＝20Kbps for each generator. Data is downloaded at a rate of c_D＝32Kbps.

Denote α_1, α_2, α_3, β, and γ for generation probability (hit ratio) of cases 1 through 5, respectively, where $\alpha=\alpha_1+\alpha_2+\alpha_3$ in all data transmission case. Reference [38] reports that each of top 100,000 contents is accessed 10,000 times or more and each of top 500,000 contents is accessed 1,000 times or more among 1,687,506 entertainment video contents in YouTube. Hit ratio for top 100,000 contents is about 6 percent and that for top 500,000 contents is about 30 percent. Looking at this YouTube case, if we assume that the data with over 10,000 accesses is stored in the edge nodes and the data with 1,000 to 10,000 accesses is stored in the core nodes, we obtain $\alpha=0.06$, $\beta=0.24$, $\gamma=0.70$ ($\beta=1-(\alpha_1+\alpha_2+\alpha_3)-\gamma$).

We assume the values of α_1, α_2, α_3 as follows.

Probability of case 1: $\alpha_1 = 0.03$.

Probability of case 2: $\alpha_2 = 0.02$.

Probability of case 3: $\alpha_3 = 0.01$.

(*$\alpha=\alpha_1+\alpha_2+\alpha_3=0.06$).

As both sending terminal (generator) and receiving terminal (consumer) are moving in this case, there might be a possibility that a mobile terminal may access to different edge nodes over time. Namely, the values of α_1, α_2, α_3 may also change frequently. However, we estimate the total amount of traffic, power consumption and node storage capacity under the above values because the objective here is to obtain rough estimates in a large-scale network. For the estimations, we also estimate the maximum flow value by assuming all terminals including wireless ones are sent and received simultaneously.

Total Traffic (Sum of Data Upload and Download)

A network is split into five communication areas like an area between outside storage devices and core nodes (between data center and core network), an area CN=CN (between the core node that data is stored and the closest core node to the metro network where receiving mobile terminal is accommodated), an area CN=EN (between a core network and a metro network), an area EN=EN (between the edge node closest to a core node and the edge node closest to terminals), and an area EN=UT.

In Case 1, the traffic in area EN=UT corresponds to $\alpha_1 c_U X+\alpha_1 c_D X$, where term including c_U is upload traffic and term including c_D is downloading. In Case 2, the amount of traffic in area EN=UT is ($\alpha_2 c_U X+\alpha_2 c_D X$) and that in area EN=EN is $\alpha_2 c_D X$, download traffic only. In Case 3, the amount of traffic in area EN=UT is $\alpha_3 c_U X+\alpha_3 c_D X$, $2\times\alpha_3 c_D X$ in areas EN=EN and CN=EN, and $\alpha_3 c_D X$ in area CN=CN. In Case 4, the amount of traffic in area EN=UT, EN=EN and CN=EN is $\beta c_U X+\beta c_D X$ and the traffic in area CN=CN is$\beta c_D X$, download only. In Case 5, the amount of traffic is $\gamma c_U X+\gamma c_D X$ for each communication area.

Table 1 shows an estimated value of the amount of traffic for each case. The total amount of traffic in each communication area is the sum of the amounts of traffic in Case 1 through 5. The table indicates that loads in each communication area in Case 1 through 3 are lower than Case 4 and 5 when the values of α_1, α_2, α_3, β, γ are set for the values in the preconditions previously described This is due to much lower values of α_1, α_2, α_3 compared to the values of β and γ. In Case 1 and 2, the amount of total traffic in each communication area is decreased by decreasing α_3, β, and γ, namely, data is not likely to be transmitted via core network because many communication areas do not produce traffic. On the other hand, we observe that the traffic 0 area in Case 1 is wider than Case 2 and Case 3. Thus, larger α_1, namely the case that an edge node storing uploaded data directly sends to the data to the receiving mobile terminal occurs frequently, can reduce the amount of traffic for each communication area (i.e., sum of the amounts of traffic from Case 1 through Case 5).

Table 1. Estimates for Total Traffic

	Case-1 (Existing at the same EN)	Case-2 (Existing at a different EN inside the same metro network)	Case-3 (Existing at an EN in a different metro network)
Outside storage device=CN	0	0	0
CN=CN	0	0	320Gbps
CN=EN	0	0	640Gbps
EN=EN	0	640Gbps	640Gbps
EN=UT	1.56Tbps	1.04Tbps	520Gbps

	Case-4 (Existing in a core network)	Case-5 (Going through outside storage device)
Outside storage device=CN	0	36.4Tbps
CN=CN	7.68Tbps	36.4Tbps
CN=EN	12.48Tbps	36.4Tbps
EN=EN	12.48Tbps	36.4Tbps
EN=UT	12.48Tbps	36.4Tbps

Table 1 shows that the amounts of traffic in each area are 52.0Tbps for EN=UT area, 50.2Tbps for EN=EN area, 49.5Tbps for CN=EN, 44.4Tbps for CN=CN area, and 36.4Tbps for outside storage devices from/to CN. The average bandwidth per link for EN=UT is c_U+c_D=52kbp. Since the average number of mobile terminals for each edge node is 344,352 as previously mentioned, the maximum amount of traffic of the area that an edge node covers is 17.9Gbps. The amount of traffic per link in EN=EN area is 50.16Tbps/363=138.2Gbps by assuming the total amount of traffic is identical in each of 363 metro networks. The amount of traffic per link in CN=EN area is 49.52Tbps/363=136.4Gbps as the same assumption as EN=EN. The amount of maximum traffic per link is 44.4Tbps/L by assuming a network is mesh topology and the amount of traffic is identical among links, where L is the number of links in a network. For example, the amount is 444Gbps if L is the same as N=100. The maximum amount of traffic per link in the area of outside storage devices is 36.4Tbps/D in the assumption that the amount of traffic is identical for each link and the number of data centers is D.

In this condition, data upload/download by local generated-data for local consumption makes the amount of traffic from outside storage devices to EN zero, which is different from upload/download via data center. Table 2 shows the total amount of traffic in each area when only data distribution in each case occurs as a reference.

Table 2. Estimates for Total Traffic in Communication Areas with Data Delivery per Case

	Only Case-1 (α_1=1)	Only Case-2 (α_2=1)	Only Case-3 (α_3=1)	Only Case-4 (β=1)	Only Case-5 (γ=1)
Outside storage device=CN	0	0	0	0	52Tbps
CN=CN	0	0	32Tbps	32Tbps	52Tbps
CN=EN	0	0	64Tbps	52Tbps	52Tbps
EN=EN	0	32Tbps	64Tbps	52Tbps	52Tbps
EN=UT	52Tbps	52Tbps	52Tbps	52Tbps	52Tbps

Total Power Consumption

Here we assume that the power consumptions of components (routers, storages, OLTs, ONUs and others) through which information are switched in upload and download are all A [W/Gbps]. We also assume that the average hop lengths for data transmission in the core network are four (i.e., 3 core routers are passed in average) [39].

Table 3 shows an estimated value of the power consumption for each case. The communication area is divided into 5 cases like the estimation of the total amount of traffic. The total amount of power consumption in the whole network is the sum of the amounts of power consumption in Case 1 through 5. In each term in the table, the term including c_U is upload and the term including c_D is download. The value except for α_1X、α_2X、α_3X、βX、γX is power consumption per access. The coefficients for c_U and c_D are the number of components in uploading and downloading.

Table 3. Calculation for Power Consumption

Outside storage device=CN	Case-1 (Existing at the same EN)	Case-2 (Existing at a different EN inside the same metro network)	Case-3 (Existing at an EN in a different metro network)
	0	0	0
CN=CN	0	0	$\alpha_3 X \times A \times (2c_D)$ 2× CR→CR
CN=EN	0	0	$\alpha_3 X \times A \times (2c_D)$ (ER→CR)+(CR→ER)
EN=EN	0	$\alpha_2 X \times A \times (3c_D)$ St+ER+(ER→ER)	$\alpha_3 X \times A \times (4c_D)$ St+ER+(ER→ER)+(ER→ER)
EN=UT	$\alpha_1 X \times A \times (4c_U+4c_D)$ (ONU+OLT+ER+St)+(St+ER+OLT+ONU)	$\alpha_2 X \times A \times (4c_U+2c_D)$ (ONU+OLT+ER-St)+(OLT+ONU)	$\alpha_3 X \times A \times (4c_U+2c_D)$ (ONU+OLT+ER+St)+(OLT+ONU)
Total	$\alpha_1 X \times A \times (4c_U+4c_D)$ [W] +	$\alpha_2 X \times A \times (4c_U+5c_D)$ [W] +	$\alpha_3 X \times A \times (4c_U+10c_D)$ [W]

Outside storage device=CN	Case-4 (Existing in a core network)	Case-5 (Going through outside storage device)
	0	$\gamma X \times A \times (2c_U+3c_D)$ (CR→Outside)+St+St+Outside+(Outside→CR)
CN=CN	$\beta X \times A \times (4c_D)$ St+CR + 2× (CR→CR)	$\gamma X \times A \times (2c_U+2c_D)$ 2× (CR→CR) +2× (CR→CR)
CN=EN	$\beta X \times A \times (2c_U+c_D)$ (ER→CR)+St+(CR→ER)	$\gamma X \times A \times (c_U+c_D)$ (ER→CR)+(CR→ER)
EN=EN	$\beta X \times A \times (c_U+c_D)$ (ER→ER)+(ER→ER)	$\gamma X \times A \times (c_U+c_D)$ (ER→ER)+(ER→ER)
EN=UT	$\beta X \times A \times (3c_U+2c_D)$ (ONU+OLT+ER)+(OLT+ONU)	$\gamma X \times A \times (3c_U+2c_D)$ (ONU+OLT+ER)+(OLT+ONU)
Total	$\beta X \times A \times (6c_U+8c_D)$ [W] +	$\gamma X \times A \times (9c_U+9c_D)$ [W]

Here we assume that the power consumption per bit transfer for a power-efficient server is 100W/Gbps (A=100). Total power consumption depends on the values of α_1, α_2, α_3, β, and γ. For example, as the preconditions mentioned above, with a use of $\alpha_1=0.03$, $\alpha_2=0.02$, $\alpha_3=0.01$, $\beta=0.24$, $\gamma=0.70$, the total power consumption in the whole network becomes

$$0.03XA^*(4c_U+4c_D)+0.02XA^*(4c_U+5c_D)+0.01XA^*(4c_U+10c_D)+0.24XA^*(6c_U+8c_D)+0.70XA^*(9c_U+9c_D)$$
$$=XA^*(7.98c_U+8.54c_D),$$

and if each parameter values in the preconditions and A=100 are substituted, the total power consumption becomes 43.3 [MW].

On the other hand, in the case of $\alpha_1=0$, $\alpha_2=0$, $\alpha_3=0.06$, $\beta=0.24$, $\gamma=0.70$, namely, the case that any receiving terminal does not receive information from the edge nodes to which the receiving terminal belongs, the total power consumption in the whole network becomes

$$0.06XA^*(4c_U+10c_D)+0.24XA^*(6c_U+8c_D)+0.70XA^*(9c_U+9c_D) = XA^*(7.98c_U+8.82c_D),$$

and the total power consumption becomes 44.2 [MW]. Thus, the condition $\alpha_1 > \alpha_2 > \alpha_3$ could slightly reduce the total power consumption in the whole network if data is obtained from edge nodes. Namely, the total power consumptions could be reduced if the information stored in the edge node is transferred in the network under the same edge node and other information is transferred within the edge networks.

As can be imagined from equations in Table 3 easily, the larger cache hit ratio in edge nodes (or core node) could obtain more of energy-saving effect by installing cache and storage in the edge nodes (or core nodes). An extreme example is a case in which all data is accessed from outside domain, Namely, in $\alpha_1=0$, $\alpha_2=0$, $\alpha_3=0$, $\beta=0$, $\gamma=1$, total power consumption becomes $XA^*(9c_U+9c_D)=46.8$[MW]. Accordingly, a dynamic information diffusive network in which cache and storage are installed in edge nodes and core nodes properly reduces total power consumption in the network. On the other hand, when all communications are fit to Case 1 ($\alpha_1=1$, $\alpha_2=0$, $\alpha_3=0$, $\beta=0$, $\gamma=0$), namely, a complete case of local generated-data for local consumption, total power consumption becomes $XA^*(4c_U+4c_D)=20.8$[MW]. In this condition, data uploading and downloading by local generated-data for local consumption ($\alpha_1=1$) is power saving of 55% compared to the extreme case of uploading/downloading to/from a data center. In a case of $\alpha_1=0.50$, $\beta=0.24$, $\gamma=0.26$, which will be shown in storage size estimation (Fig. 25), and where half of data is local generated-data for local consumption, the total power consumption in the whole network becomes 31.6 [MW] and this concludes power saving of 33% compared to data center uploading/downloading case.

Table 4 shows total power consumption when all data is distributed by each case only as a reference. As can observed from the table, the power consumption by servers and storages are constant regardless of their locations but the power consumption by communication equipment is quite different. The closer installation to consumer decreases power consumption by the communication equipment. Moreover, user service is improved because consumers' (users') data access times are decreased

Table 4. Estimates for Power Consumption with Data Deliver per Case

	Only Case-1 (α_1=1)	Only Case-2 (α_2=1)	Only Case-3 (α_3=1)	Only Case-4 (β=1)	Only Case-5 (γ=1)
Server/Storage	5.2MW	5.2MW	5.2MW	5.2MW	5.2MW
Core/Outside storage device	0MW	0MW	9.6MW	11.6MW	20.8MW
Metro	5.2MW	8.4MW	14.8MW	10.4MW	10.4MW
Access	10.4MW	10.4MW	10.4MW	10.4MW	10.4MW
Total	20.8MW	24.0MW	40.0MW	37.6MW	46.8MW

Although A=100 is assumed to all components in the above estimation, in reality, power consumptions of all components are not always identical. There are components of which power consumption are quite large (for example, optical network unit (ONU [40]) in access network [40]). Further power reduction appears by more power saving of component,.

Moreover, when source terminals and destination terminals are moving from a network to some of other networks, α_1, α_2, α_3 are likely to change frequently. A network design and a data distribution mechanism that can maintain the relation of$\alpha_1 > \alpha_2 > \alpha_3$ are required. Moreover, compared case 3 with case 4, the power consumption in case 3 increases sum of the power consumptions more with $\alpha_3 \geqq \beta$. Accordingly, α_3 can be kept as small as possible. And therefore, a network design and a data distribution mechanism that can avoid data acquisition from metro network to which a consumer does not belongs as much as possible are required.

Node Storage Capacity

It is assumed that frequent access information is stored in a node close to consumers (receiving terminals) in the above estimation. It is also assumed that the information stored in each edge node is unique and volume of information is not distributed uniformly among edge nodes. Information stored in core nodes is also assumed so. However, in this calculation, it is assumed that all information in a network is stored in a single edge node and maximum value of required storage capacity per edge node is derived. That of a core node is also derived.

The node storage capacity can be derived by the equation of "information size" times "number of information stored in the node storage". As for information size, it is assumed that data is always uploaded. Information size generated in one day (86,400 seconds) is 216MB for c_U=20Kbps. Then, the number of information sources stored in each node-storage is estimated. Denote C [number of accesses per day] for the total number of information accesses per day (information may be duplicated). In Reference [41], the number of accesses for each content follows by Zipf-like distribution that is similar to Zipf-law. We calculate Zipf-like distribution for our estimation. Zipf-like distribution is described as follows.

$$f(k) = \left\{ \frac{(1/k)^P}{S} \right\}$$

*$k=1, 2, \ldots, K_N$

*$0<P<=1$ (When P=1, Zipf law)

*$S=(1/K_N)^P$ (→ Normalized so that the number of access to $[K_N]$th content is equal to $f(K_N)=1$.)

K_N is defined as total number of contents (information in this paper). Fig. 24 shows the number of accesses for contents. As shown in the figure, the sum of the numbers of accesses of 1 through K_1 in the horizontal axis becomes cache hit ratio $\alpha(=\alpha_1+\alpha_2+\alpha_3)$ at edge node caches. The sum of the numbers of accesses of (K_1+1) through K_2 becomes cache hit ratio β at core node caches. The sum of the numbers of accesses of (K_2+1)

through K_N becomes hit ratio γ at outside of network domain (information is hit at neither edge nor core) .

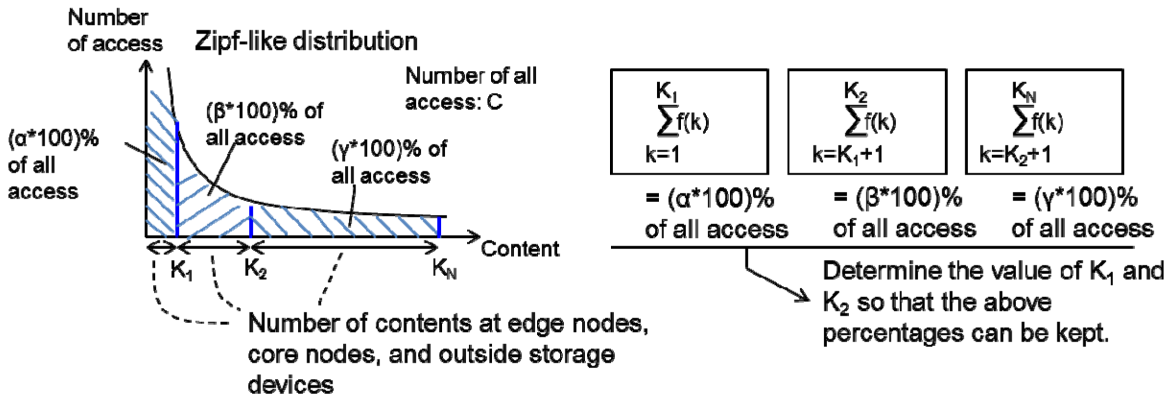

Fig. 24. Traffic to Content

In this numerical calculation, if we assume that each receiving terminal accesses 20 of information for each day in average, the total number of information accesses per day becomes C=1 billion * 20＝ 20 billion accesses. P=0.8 is set for this calculation. As described in the preconditions, when α=0.06, β=0.24, γ=0.70 are set, “K_N=4.5 billions” makes the number of accesses from top 1 to top K_N 20 billion. We also obtained K_1=5,193 and K_2=8,194,158. Namely, the numbers of information stored in edge node storage, core node storage, and outside storage of network domain are “5,193”,” 8,194,158”, and 4.5 billion, respectively. In conclusion, the storage capacities (maximum) for edge node, core node, and outside of network domain, become 1.122TB, 1.77PB, and 972PB, respectively.,

Fig..25 shows node storage capacity (maximum) for hit ratio (α) at edge node. Here, β=0.24 is fixed and γ=1-α-β. The vertical axis is log-scale. As explained in the power consumption estimation, larger α than β and γ reduces power consumption needed for information distribution from outside storage of network domain and reduces the total power consumption is the whole network. However, as can be shown in Fig. 25, the storage capacity required for edge nodes and core nodes is increased. The edge node storage capacity is more than 1TB at α＝0.06 and more than 10TB at α＝0.10. The core node storage capacity is more than 1PB at α＝0.03 and more than 10PB at α＝0.19. Developing such storage device and node device with a reasonable cost makes market entry easier.

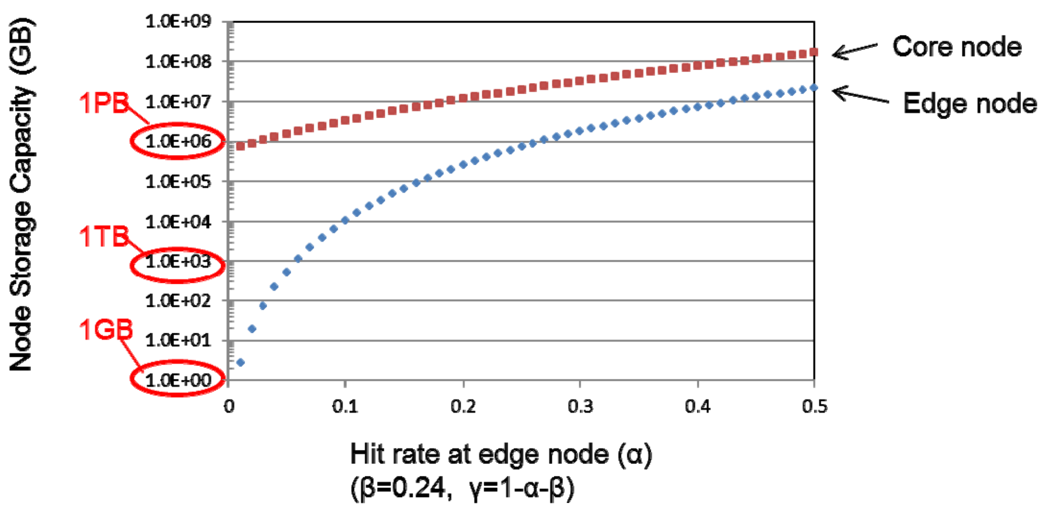

Fig. 25. Edge-Node Cache Hit Ratio vs Node Storage Capacity (Mobile Terminal)

7.2 Numerical Calculation for PC Terminals (download-only)

In this subsection, we estimate the total amount of traffic, total power consumption, and total node cache capacity when sending and receiving terminals are fixed ones. The fixed terminals are categorized into the M2M fixed terminals such as fixed sensors and safety cameras and the fixed terminals such as personal computers for communications via FTTH (Fiber-To-The-Home) and FWA (Fixed Wireless Access). The latter is the target of this calculation.

A feature different from the case of mobile terminals is that uploading data is not always sent from sending terminals. Therefore, the target of calculation is downloaded only, namely, the case that receiving terminals obtain data that has already been stored in somewhere of the network. Moreover, when uploading, data is stored in outside storage of the network (e.g., data center) at first, and part of data is copied from the outside storage to edge nodes and core nodes depending on the popularity. The action of the copy is also regarded as downloading. However, copy mechanism is designed such that duplication of the upload (data in an edge node is copied to core node) is avoided. Fig. 26 shows dataflow in a dynamic information diffusive network in the case of the fixed terminals. Different from the model of mobile terminals, there are 3 cases, that a terminal acquires data from the closest edge node (Case 1), that it acquires data from a core node (Case 4), and that it acquires data from outside storage from the network domain (Case 5).

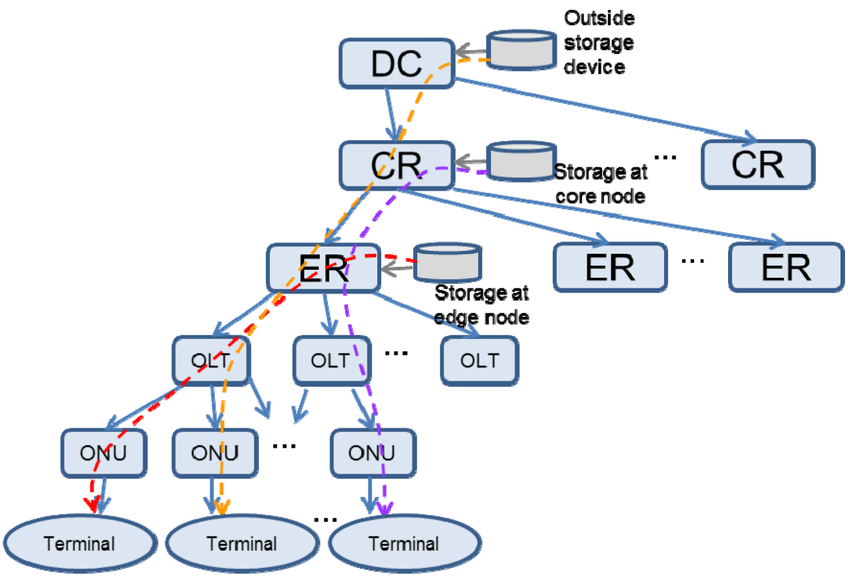

Fig. 26. Dataflow of Dynamic Information Diffusive Network in PC Terminal (Download)

<u>Preconditions for Various Calculations</u>

The number of fixed terminals X is set to 40 million because the number of subscribers to broadband network in Japan reaches 35,529,000 at the time of June 2011. Similar to the calculation for the mobile terminal model, the number of edge nodes N is set to 2,904 and the number of core nodes M is set to 100. Namely, the average number of subscribers to the fixed broadband network becomes 13,774 per edge node. Assuming that video quality sent from a sending terminal to the storage is similar to YouTube quality, bitrate is set to c = 8 Mbps. In all downloading case, generation probability (node cache hit ratio) of Cases 1, 4, and 5 in Fig. 23 is as follows, which is the same condition as in the mobile terminal model.

・Hit ratio at edge node cache: $\alpha=0.06$

・Hit ratio at core node cache: $\beta=0.24$

・Hit ratio at outside of network domain (ratio that hit does not occur in edge nodes and core nodes) $\gamma=0.70$

For the estimations of the total amount of traffic and the total power consumption, we assume that all terminals communicate simultaneously. The maximum flow is estimated.

<u>Total Traffic (Downloading only)</u>

A network is split into five communication areas like an area between outside storage devices and core nodes (between data center and core network), an area CN=CN (between the core node that data is stored and the closest core node to the metro network where receiving mobile terminal is accommodated), an area CN=EN (between a core network and a metro network), an area EN=EN (between the edge node closest to a core node and the edge node closest to terminals), and an area EN=UT.

In Case 1, the traffic in the area EN=UT corresponds to ($\alpha c_D X$) and the traffic in other areas is ($\alpha c_D N$). In Case 4, the amount of traffic in the area EN=UT, EN=EN and CN=EN is ($\beta c_D X$) and the traffic in the area CN=CN and between outside storage devices and core nodes is ($\beta c_D M$). In Case 5, the amount of traffic is ($\gamma c_D X$) for each communication area.

Table 5 shows estimated amount of traffic in each case. The sum of Case 1, 4, and 5 at each communication area becomes the total amount of traffic.

This table indicates that loads in each communication area in Case 1 are lower than Case 4 and 5 when the values of α, β, and γ are set to the preconditions. This is due to much lower value of α_1 compared to the values of β and γ. In Case 1, the amount of total traffic (the sum of traffic in cases 1, 4, and 5) in each communication area is decreased by decreasing β, and γ, namely, data is likely to be transmitted via edge node because many communication areas do not produce traffic (Gbps class). The amount of traffic between outside network domain and core node and between CN and CN in Case 1 is larger than that in Case 4. However, since required amount of traffic calculated as the sum of all CN=CN pairs is 1.39Gbps, installation seems not so difficult and therefore, no problem occurs.

As already described, it is assumed that part of data is copied from outside storage of network domain to edge node or core node depending on its popularity. Outside domain to EN (1.39Gbps) in Case 1 and outside domain to CN (192Mbps) in Case 4 in Table 5 are the cases. An example method for copying data to edge node or core node is information data transfer by using multicast routing protocol based on location IDs of all edge nodes and all core nodes.

Table 5. Estimates for Total Traffic

	Case-1: Obtain from edge node	Case-4: Obtain from core node	Case-5: Obtain from outside storage device
Outside storage device=CN	1.39Gbps	192Mbps	224Tbps
CN=CN	1.39Gbps	192Mbps	224Tbps
CN=EN	1.39Gbps	76.8Tbps	224Tbps
EN=EN	1.39Gbps	76.8Tbps	224Tbps
EN=UT	19.2Tbps	76.8Tbps	224Tbps

Table 5 shows that the amounts of traffic in each area are 320Tbps for EN=UT area, 300.8Tbps for EN=EN area, 300.8Tbps for CN=EN, 224Tbps for CN=CN, and 224Tbps for outside storage devices to CN. The average bandwidth per link for EN=UT becomes c_D=8Mbps. Since the average number of mobile terminals for each edge node is 13,774 as previously mentioned, the maximum amount of traffic of the area that an edge node covers becomes 110.19Gbps. The amount of traffic per link in EN=EN area becomes 300,8Tbps/363=828.65Gbps by assuming the total amount of traffic is identical in each of 363 metro networks. The amount of traffic per link in CN=EN area becomes 300.8Tbps/363=828.65Gbps as the same assumption as EN=EN. As for CN=CN area, the amount of maximum traffic per link becomes 224Tbps/L by assuming a network is mesh topology and the amount of traffic is identical among links, where L is the number of links in a network. For example, the amount becomes 2.24Tbps if L is the same as N=100. The maximum amount of traffic per link in the area of outside storage devices becomes 224Tbps/D in the assumption that the amount of traffic is identical for each link and the number of data centers is D. 22.4Tbps is calculated if D=10.

In this condition, data download from edge nodes reduces the amount of traffic from outside storage of network domain to edge nodes compared to data download from data center. As a reference, Table 6 shows the total amount of traffic in each area when only data distribution in each case occurs.

Table 6. Calculation for Total Traffic in Communication Areas with Data Delivery per Case

	Only Case-1 (α_1=1)	Only Case-4 (β=1)	Only Case-5 (γ=1)
Outside storage device=CN	23.2Gbps	800Mbps	320Tbps
CN=CN	23.2Gbps	800Mbps	320Tbps
CN=EN	23.2Gbps	320Tbps	320Tbps
EN=EN	23.2Gbps	320Tbps	320Tbps
EN=UT	320Tbps	320Tbps	320Tbps

Total Power Consumption

Here we assume that the power consumptions of components (routers, storages, OLTs, ONUs and others) through which information are switched in downloading are all A [W/Gbps]. We also assume that the average hop lengths for data transmission in the core network are four (i.e., 3 core routers are passed in average) [39].

Table 7 shows an estimated value of the power consumption for each case. The communication area is divided into 3 cases like the estimation of the total amount of traffic. The total amount of power consumption in the whole network is the sum of the amounts of power consumption in all cases. In each term in the table, the value except for αN, αX, βM, βX, and γX is power consumption per access. The coefficients for c_D are the number of components in downloading.

Table 7. Estimates for Total Power Consumption

	Case-1: Obtain from edge node		Case-4: Obtain from core node		Case-5: Obtain from outside storage device	
Outside storage device=CN	$\alpha N \times A \times (3c_D)$	St+Outside +(Outside→CR)	$\beta M \times A \times (3c_D)$	St+Outside+ (Outside→CR)	$\gamma X \times A \times (3c_D)$	St+Outside+ (Outside→CR)
CN=CN	$\alpha N \times A \times (2c_D)$	2×(CR→CR)	$\beta M \times A \times (3c_D)$	2× (CR→CR)+St	$\gamma X \times A \times (2c_D)$	2× (CR→CR)
CN=EN	$\alpha N \times A \times (c_D)$	(CR→ER)	$\beta X \times A \times (3c_D)$	St−CR+(CR→ER)	$\gamma X \times A \times (c_D)$	(CR→ER)
EN=EN	$\alpha N \times A \times (2c_D)$	(ER→ER) +St	$\beta X \times A \times (c_D)$	(ER→ER)	$\gamma X \times A \times (c_D)$	(ER→ER)
EN=UT	$\alpha X \times A \times (4c_D)$	St+ER +OLT+ONU	$\beta X \times A \times (2c_D)$	(OLT+ONU)	$\gamma X \times A \times (2c_D)$	(OLT+ONU)
Total	$A \times (\alpha N \times (8c_D) + \alpha X \times (4c_D))$ [W] + $A \times (\beta M \times (6c_D) + \beta X \times (6c_D))$ [W] + $\gamma X \times A \times (9c_D)$ [W]					

Here we assume that the power consumption per bit transfer for a power-efficient server is 100W/Gbps (A=100), which is similar to the mobile terminal case. Total power consumption depends on the values ofα, β, and γ. For example, as the preconditions mentioned above, with a use of α=0.06, β=0.24, γ=0.70, the total power consumption in the whole network becomes 251.52 [MW] if each parameter values in the preconditions are substituted. On the other hand, in the case of α=0, β=0, γ=1, namely, the case that any receiving terminal receives information from outside storage of network domain, the total power consumption in the whole network becomes 128.0 [MW]. The total power consumption can be reduced by storing the high popularity information in edge nodes for directly downloading from the edge nodes (not via core nodes) by terminals. Accordingly, a dynamic information diffusive network in which cache and storage are installed in edge nodes and core nodes properly reduces total power consumption in the network. Table 8 shows the total power consumption when all data is distributed by each case only as a reference. In this condition, data downloading from edge networks (α=1) is power saving of 55% compared to an extreme case of downloading from a data center (γ=1). Similar to the case of downloading by mobile terminals, in the case of downloading by fixed terminals, the closer installation to consumer decreases power consumption by the communication equipment. Moreover, user service is improved because consumers' (users') data access times are decreased

In a case of α=0.50, β=0.24, γ=0.26, which will be shown in storage size estimation (Fig. 27), and where half of data is local generated-data for local consumption, the total power consumption in the whole network becomes 153.0 [MW] and this is power saving of 47% compared to data center downloading case.

Table 8. Estimates for (Total) Power Consumption with Data Delivery per Case

	Only Case-1 (α_1=1)	Only Case-4 (β=1)	Only Case-5 (γ=1)
Server/Storage	32.0MW	32.0MW	32.0MW
Core/Outside storage device	9.3KW	32.0MW	128.0MW
Metro	32.0MW	64.0MW	64.0MW
Access	64.0MW	64.0MW	64.0MW
Total	128.0MW	192.0MW	288.0MW

* Calculating the value to one place of decimals (rounding off)

Node Storage Capacity

It is assumed that frequent access information is stored in a node close to consumers (receiving terminals). The node storage capacity can be derived by the equation of “information size” times “number of information stored in the node storage”. 1GB of information size is used by assuming that movie file up to 15 minutes and 29 seconds (equivalently 8Mbps) can be uploaded like YouTube. Then, the number of information sources stored in each node-storage is estimated. Denote C [number of accesses per day] for the total number of information accesses per day (information may be duplicated). Like the case of mobile terminal model, it is assumed that the number of accesses for each content follows by Zipf-like distribution [41]. The length of each information source is set at 15 minutes and each person watches these videos for 2 hours in average per day. Thus, C = 40 million * 8 = 320 million accesses per day because each person accesses 8 video sources in average per day. As described in the preconditions, when α=0.06, β=0.24, γ=0.70 are set, “K_N=70 million” makes the number of accesses from top 1 to top K_N 320 million. We also obtained K_1=202 and K_2=154,384. Namely, the numbers of information stored in edge node storage, core node storage, and outside storage of network domain are “202”,” 154,384”, and 72 million, respectively. In conclusion, the storage capacities (maximum) for edge node, core node, and outside of network domain, are 202GB, 154.384TB, and 72PB, respectively.,

Figure 27 shows node storage capacity (maximum) for hit ratio (α) at edge node. Here, β=0.24 is fixed and γ=1-α-β. The vertical axis is log-scale. As explained in the power consumption estimation, larger α than β and γ reduces power consumption needed to information distribution from outside storage of network domain and reduces the total power consumption is the whole network. However, as can be shown in Fig. 27, the storage capacity required for edge nodes and core nodes is increased. The edge node storage capacity is more than 1TB at α=0.10 and more than 10TB at α=0.17. The core node storage capacity is more than 100TB at α=0.04, more than 1PB at α=0.21 and more than 10PB at α=0.48.

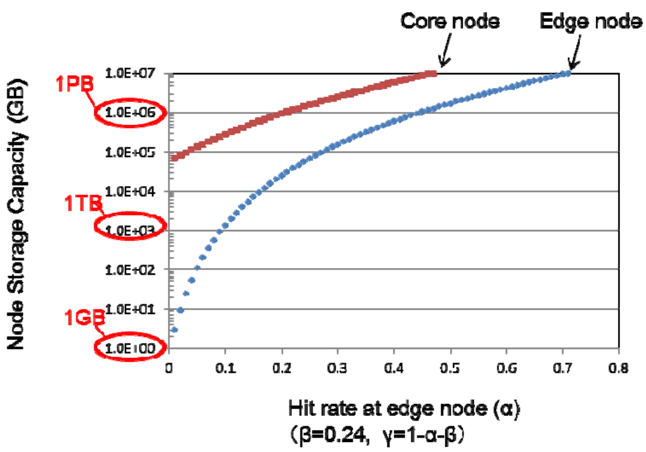

Fig. 27. Edge-Node Cache Hit Ratio vs Node Storage Capacity (PC Terminal)

8 Overseas Trend

- CCN/NDN (Content-Centric Networking/Named Data Networking)

  CCN is the network architecture [8] to perform communication based on content names (IDs) and has the following features. It communicates with using not location-dependent address (IP address) but content name (ID). Terminals are not required awareness of the locations of the opposite-side's objects in the communication. Each ID has a readable ID, which are corresponding to URL. With content caching and relay by the relay node, an end-to-end communication between terminals will not be needed. CCN does not authenticate and encrypt the communication path between terminals (IPSec, SSL, etc.) but encrypts content itself and authenticates the content at a relay node. It uses an ID as public key. It conducts data transfer by sending interest packet to upstream and by replying data packet to downstream. The interest packet is transferred by the longest prefix matching retrieval of an ID. The information in cache is held until it is deleted according to the rules of LRU or LFU. NDN [10] is one of the Future Internet Architecture (FIA) projects in the US NSF based on CCN.

- Mobility First

  MobilityFirst [11] is one of the Future Internet Architecture (FIA) projects in the US NSF and consists of nine universities including Rutgers University. It is launched in September, 2010. Their goal is to switch the network being accessed by 10 billion devices, contents and users to a mobile communication-centric design. They do the design to support robustness for the signal degradation in wireless communication and mobility of the network itself. The design includes strong security and privacy functions in the network architecture for those provisions. Additionally, it equips a tolerance for attack to the network.

  In regard to content distribution, a name and address are treated separately. For that, it introduces GUID (Globally Unique Flat Identifier) and also a function to do mapping the GUID and network address. For its realization, mapping for ID and locator is conducted by the distributed hash table with using the servers that physically distributes a flat and global namespace and also using a method called late binding. An advertisement to the neighboring nodes is also conducted in every object update to synchronize the mapping information. As for security, the above-mentioned GUID is used as public key to establish a distributed trust structure. For smooth information delivery, routing which is suited for the size of storage or the link quality needs to be conducted.

- IoT-A(Internet of Things Architecture)

  IoT-A [42] is the flagship project in Europe FP7 and is intended to develop the architecture reference model that can collaborate for the future IoT. The objective of the IOT-A project is to provide the architecture reference model for ensuring the connectivity of IoT system. "Things" here means a machine with sensor and actuator functions in the real world. Their mutual information exchange provides the architecture that can interact with each other. They are also intended to develop the architecture reference model related to the society and business by targeting multiple entities with different characteristics. For that, it is essential to form an architecture design through input from outside besides developer's know-how. In order to obtain input from outside, they have conducted questionnaires to the individuals and companies (stakeholders) who are interested in the realization of IoT architecture and created a report by summarizing the results. Additionally, the requirement documents and architecture reference model documents are disclosed. Furthermore, they are intended to distribute a list of the obtained requirements widely and acquire feedbacks for the design of the architecture reference model and the development of the architecture verification model.

- NetInf(Network of Information)

  NetInf [12] is the ID/Locator separated network architecture being proposed in the Europe FP7 project called 4WARD. NetInf links Information Object (IO) describing high-level semantics to Data Object (DO) describing bit sequence of the actual information. Furthermore, NetInf conducts mobility management for ID routing with using hierarchized multiple DHT (MDHT: Multiple DHT).

- CONET

CONET is the network architecture based on CCN which is proposed in the Europe FP7 project called CONVERGENCE [43]. CONET utilizes a cache function as a CCN's advantage and also takes action on issues including transition cost and scalability from the currently existing IP network, which is a CCN's disadvantage. CONET combines IP network and CCN by putting the unique CONET information into the IP option header or extension header. CONET also prevents routing table from overload by caching with an upper limit on the number of the routing information.

- SENSEI (Integrating the Physical with the Digital World of the Network of the Future)
  SENSEI [44] is an EU FP7 project completed in 2010. An architecture as its outcome is summarized in the white paper "reference architecture to link the physical and the digital world in the network of the future". The system model for SENSEI adopts the architecture that "Resource" to describe entity (device) in the real world and a software component "Resource End Point" to control it are separated and moreover those resources are implemented in different hosts. Although this realizes the abstraction of interaction with the real world, this abstraction includes all the information to realize interactions such as device functions and gateway control information for network access. The framework for SENSEI identifies a list of the resource that meets the requirements by resource directory (RD) and associates the list with the entity by entity directory (ED). Furthermore, the SENSEI architecture fulfills semantic query resolver and enables the discovery of resources via RD and ED and its access based on the semantic level of description. The information model defines the three layers of the law data generated by sensors, Observation and Measurement (O&M) added metadata based on the low data and the context data further added supplementary information in order to implement a flexible method for information access. With a view to semantics application for describing information, resource description format (RDF) is adopted. Moreover, SENSEI introduced definitions for AAA function, ID management, privacy management, advanced function to actuation and operation management function as elements of the service platform.

- FLORENCE (Multi Purpose Mobile Robot for Ambient Assisted Living)
  FLORENCE [45] is an EU FP7 project launched in 2010 and is intended to verify the reduction in various costs to improve and maintain the quality of life for the elderly with the utilization of IoT technology. The project conducts research on the service platform technology for the model that conducts data collection and processing for living environment by combining multiple technologies including biological sensors, home automation and robot with a built-in sensor and also feedbacks by actuator and rich communication. In the interim report issued in January 2011 [46], definitions of the service requirements and architectural overview for the service platform are reported. The architecture is established with a focus on the requirements for incorporating robots into services and the context processing function.

- 4WARD/Vnet, SAIL/CloNe
  4WARD [47] is an EU FP7 project that widely studies the future network architecture without depending on the specific physical layers and was implemented in 2008-2009. WP-3 (Working Package – 3) of the 4WARD is VNet, and it has conducted research and development on the virtual network architecture with collaboration with industries and universities including Ericsson and University of Bremen. VNet reviews ISP and SP (Service Provider: assuming Google or Amazon) as the roles of the existing Internet, defines 4 kinds of roles (single player can be dual players) called InP/PIP ((Physical) Infrastructure Provider), VNP (Virtual Network Provider), VNO (Virtual Network Operator) and SP (Service Provider), and proposes advantages of virtualization viewed from each role. With the separation of the role of the existing ISP into InP, VNP and VNO, concentration and selection of the management resources in each role can be easier. And moreover, it is proposed that there would be an advantage of the increased choices for collaboration with other roles. Although GENI has a single clearing house which is equivalent to VNP, VNet has multiple VNPs from a business perspective. Thus, 4WARD features the studies not only in the engineering point of view but in the business point of view. These activities have been carried over into SAIL/Clone [48] (to be implemented in 2010-2013), which is a successor project of 4WARD/VNet, and they are intended to control the virtual resources that integrate a networking called flash network slice with its computing by newly introducing the element for computing.

9 Conclusion

A key to develop a new business is how quickly to grasp user's as consumers values including their preferences and reflect them to services. For that, it is regularly necessary to acquire and analyze information on the network, change it to the valuable information, and realize the ubiquitous structure around users. Also, the structure needs to be an easily available for new service providers as well. The amount of the mobile terminal traffic increases at an annual rate of 90%, and it is said that the M2M traffic will be reached to 300 petabyte per month by 2015. The new generation network has the potential to create unlimited values by distributing such information.

Here we have proposed the network architecture (Dynamic Information Diffusive Network) suitable for information distribution, which processes information from users or devices regardless of fixed or mobile terminals depending on the situation when needed, and that appropriately arranges on the network for distribution. This is the information distribution network architecture that realizes not only the way of mere information collection and/or exchange but also a set of processes for providing users with value-added useful information. The dynamic information diffusive network realizes operational cost reduction in network itself or its services, and at the same time, realizes the provision of platform and infrastructure for newly value-added services such as M2M and content delivery with future growth potential. In particular, it ensures the efficient access to the dynamic information sent from one billion mobile terminals or 100 billion sensors and actuators per network carrier and the efficiencies in both information distribution and energy utilization through a simple mobile communication control of terminals or information, a cache function to hold the information, an arrangement of the storage function into the network and its efficient distribution, and the synthesis of information in the network. For network carriers, they could take advantages in terms of bandwidth, power consumption or operation, include service platforms such as content delivery and M2M services in their businesses and conduct infrastructure development that is linked to those services.

Toward these goals, here we have established the network architecture as high-value added platform for new services, introduced clarification of the stakeholders and the principles of competition, and proposed the enabling technologies to develop the value-added information distribution network business in 2020. Moreover, we have mentioned not only the goals and enabling technologies but the framework of information distribution functions, from information generation to information receiving by consumer, in order to realize the dynamic information diffusive network. As the next step, we will work on the functional segmentation on information distribution for the network and develop the guidelines for building the whole network with expecting the establishment of the enabling technologies. This way, we promote the establishment of the network in order to realize an early prototype in 2015 and develop the network business in 2020 as mentioned in this document. And that is, taking content distribution for example, the early prototype will be realized and the superiority over the current existing content distribution will be clarified. Then a business model consistent with the simulated information distribution in 2020 will be established.

Appendix

- CDN (Content Delivery Network)
  A service network which stores information in advance and once receiving a request for information distribution, the network sifts out a location of the information and then transmits the information to the requestor.
- CCN (Content Centric Network)／DCN (Data Centric Network)
  A service network which stores dynamically-generated information with a given ID and once receiving a request for information distribution, the network sifts out a location of the information and then transmits the information to the requestor. Attention is that the destination of the information is not limited to end users but the information will occasionally be new information by additional processing of the information.
- Search Service
  Collecting information by periodically crawling the Web servers to compile a database. Once receiving a request, a list of its information is provided. However, the contents are not delivered.
- Contents
  Valuable information for users as well as consumers. These are generated by a generator or in-network processing function based on data.
- Data
  Information generated by a generator. It requires analysis or seems no good enough value for users like sensing information from sensors or information broadcasted without reference to the users' want value.
- M2M (Machine-to-Machine) Communication
  A communication form between unattended devices such as a sensor and an actuator, not conducted by people like Web access.
- Dynamic Information Diffusive Network
  An information distribution network which processes dynamically-generated information from users or ubiquitous devices regardless of fixed or mobile ones when needed and places on the network appropriately for distribution.
- ID/Locator Separation
  Separating an ID of devices or contents from its location (place or IP address) for identification and controlling them as separate identifiers.
- User ID
  Assigned to a user to uniquely identify the user in the network. User IDs are used to search, authenticate, authorize and bill the user for a service.
- Data and Contents ID
  Assigned to a data or content to uniquely identify it independent of its location or owner. The use of data/content IDs would be helpful to create a new network architecture based on an information-centric paradigm and to enhance data security in the information node processing or the content delivery. This feature is also helpful for content mobility and caching.
- Service ID
  Can further be divided into two subcategories: content service ID and network service ID. A content service ID specifies an application service and associates with service related attributes, such as the security keys, sequence numbers, and states. The content service IDs would be mainly used by servers and client nodes to identify the services. A network service ID will specify a data forwarding service provided by the network nodes. It may specify a logically isolated network partition (LINP) in network virtualization, VLAN, or a particular protocol used for handling data packets (e.g. forwarding, queuing, QoS support) in the network.
- Node ID
  Assigned to a physical or virtual device to uniquely identify it independent of its location in the network. The node ID would be used for access control of mobile nodes, trust establishment between nodes, and to identify communication sessions existing between the nodes.
- Location ID
  Also called a locator and assigned to a device or node to locate it in the network topology. The locator is used by the routing infrastructure to locate the node uniquely in the network topology. Locator formats are dependent on the network layer protocols or routing protocols which are used to locate the destination node and forward data towards it through the network.

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