SWIFT: Softwarization of Intelligence for Efficient 6G Mobile Networks

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TOHOKU UNIVERSITY

Outline

Introduction

SWIFT Framework

Preliminary Results

- T1: Generation, Validation, and Characterization of Dynamic WiGig Datasets
- T2: Development of Efficient Prediction Models in the WiGig
- T3: Development of Agile Data-driven Resource Management Strategy

Conclusion and Future Work

Introduction (1/2)

- 90% of future data traffic will be due to virtual reality, augmented reality, ultra-HD video, etc.
- Requirement: multi-Gbps data rate and 7 – 10 ms delay
- WiGig can deliver 4.6 Gbps with 10 ms delay!
- Challenge: channel dynamics with user mobility (blockages)

Introduction (2/2)

- Intelligent resource management: link assignment and handover ➔ maintain connectivity with mobility
- General channel models are inaccurate ➔ data-driven approach
- Given link state data, train ML model to decide handovers
- Limitation: channel statistics vary with environment dynamics!

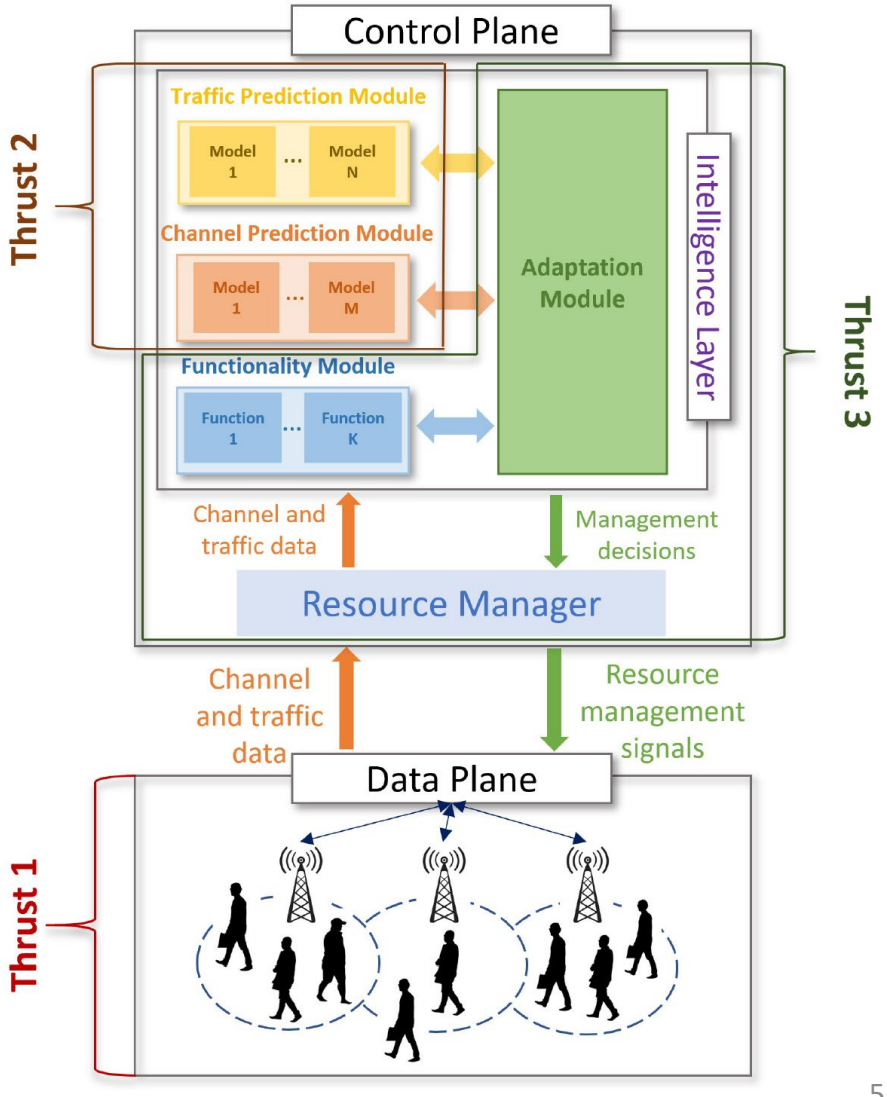
Develop *agile* data-driven strategies that adapt to spatio-temporal varying dynamics and provide stable high quality WiGig connections

SWIFT ➔ SoftWarization of Intelligence for eFficient 6G Mobile NeTworks

extends the control plane of the SDN architecture to provide *flexible in-network intelligence*

SWIFT Framework

- Adaptation Module: Adapts to the environment dynamics
- Prediction Module: Predict future channel and traffic conditions
- Functionality Module: Pro-active link assignment based on the current and future conditions



Research Thrusts

T1: Generation, Validation, and Characterization of Dynamic WiGig Datasets

Novel methods are proposed to generate the datasets at a *reduced complexity of three orders of magnitude*.

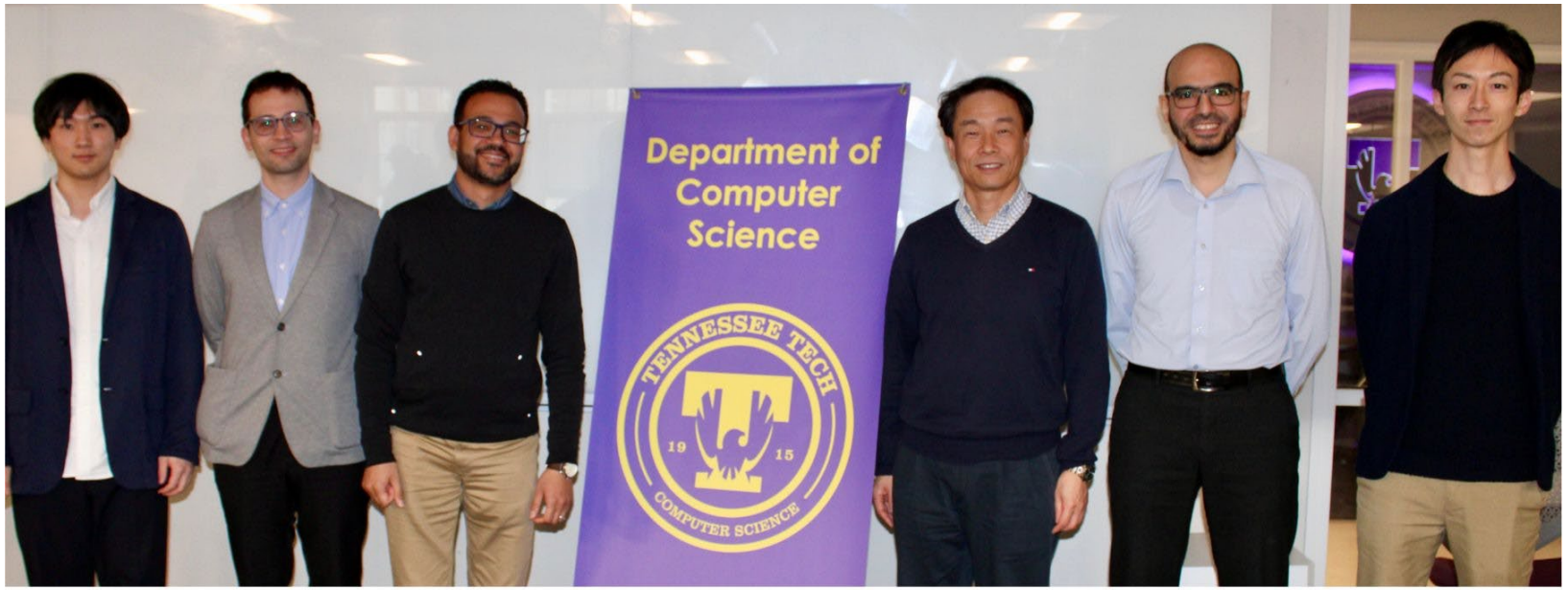
T2: Development of Efficient Prediction Models in the WiGig

Novel methods are proposed to predict with *high accuracy* the channel gain, traffic load at APs, and traffic type/UE.

T3: Development of Agile Data-driven Resource Management Strategy

Novel methods are proposed to decide link assignment function that adapt to the environment dynamics and *maintain stable link quality*.

Research Collaboration



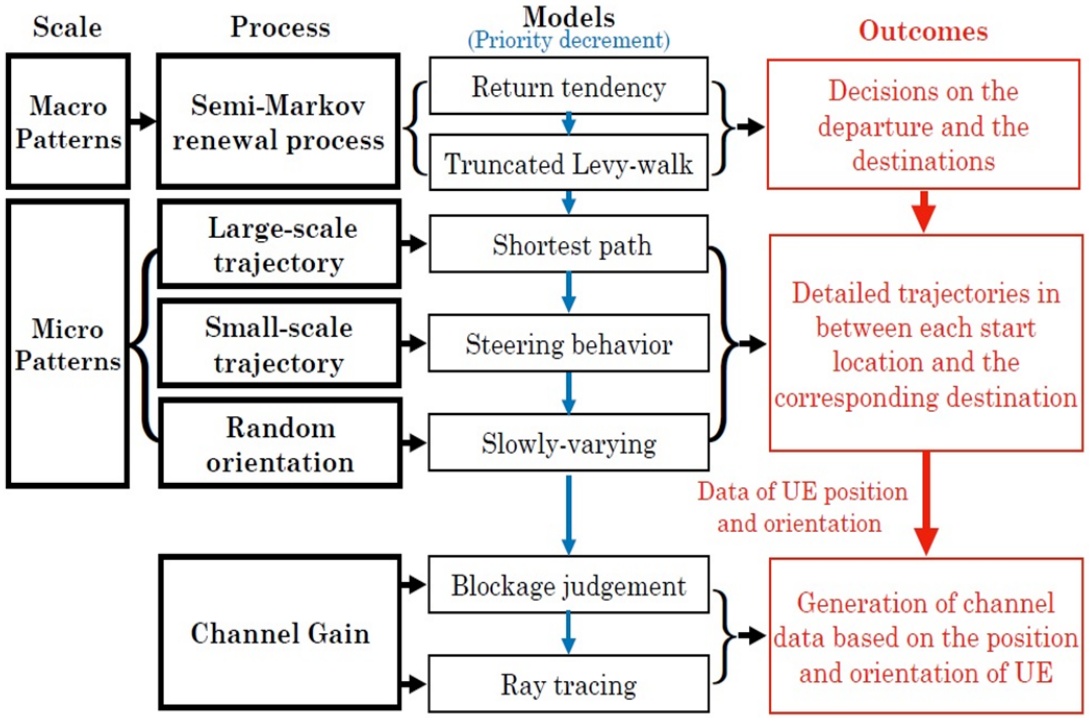
Tennessee Tech University, January 31st, 2023

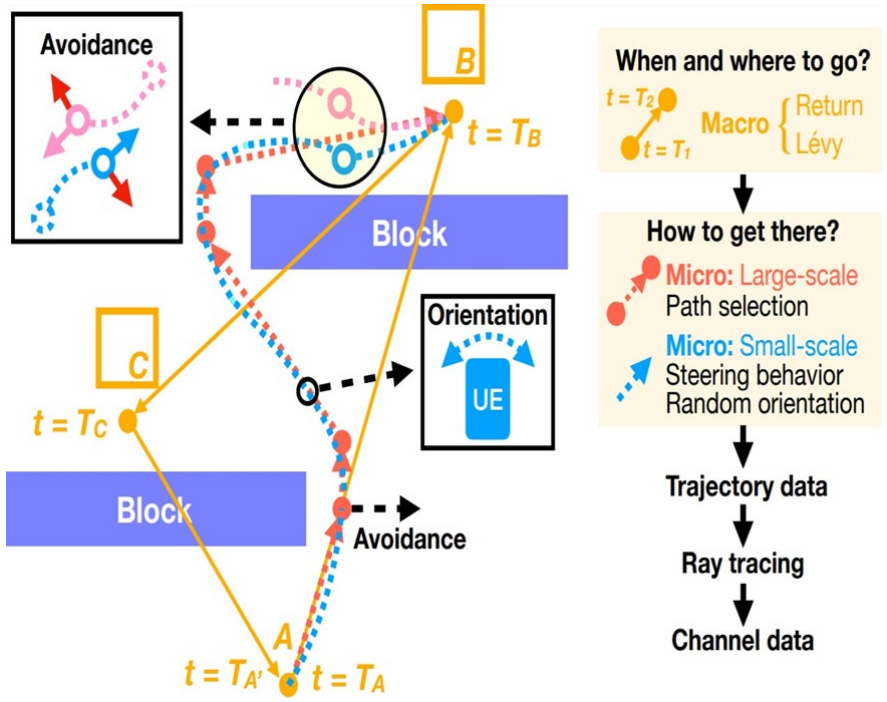
Dataset Generation (1/3)

Preliminary Work:

Two-timescale Mobility
- Macro ➔ Next destination point
- Micro ➔ Detailed trajectory and orientation

→ Channel

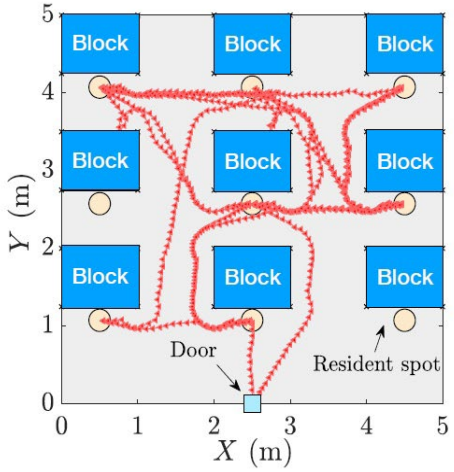


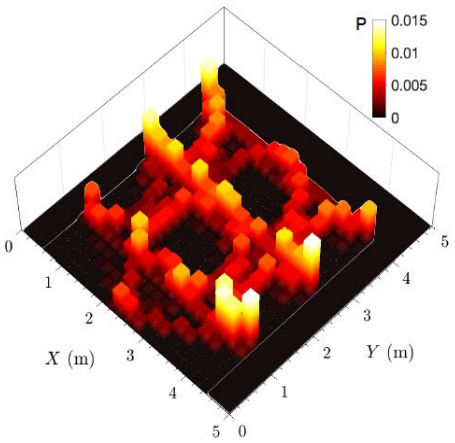


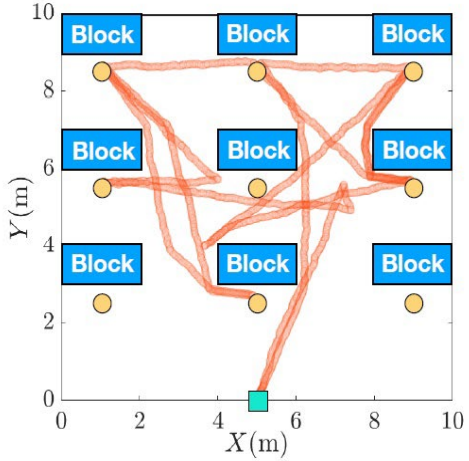
Dataset Generation (2/3)

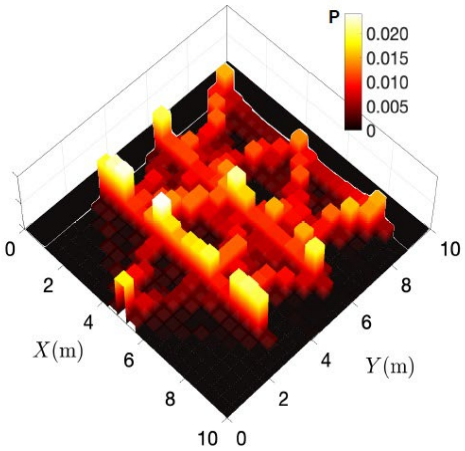
Preliminary Work:

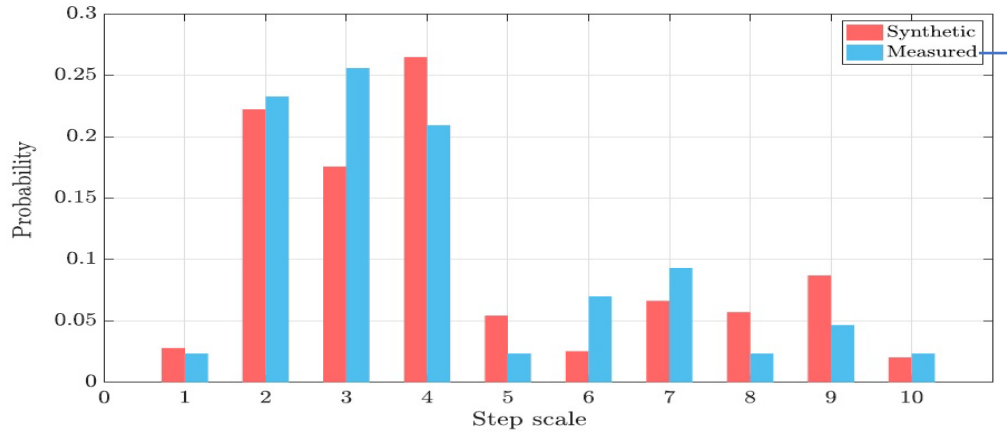
Synthetic Mobility Traces







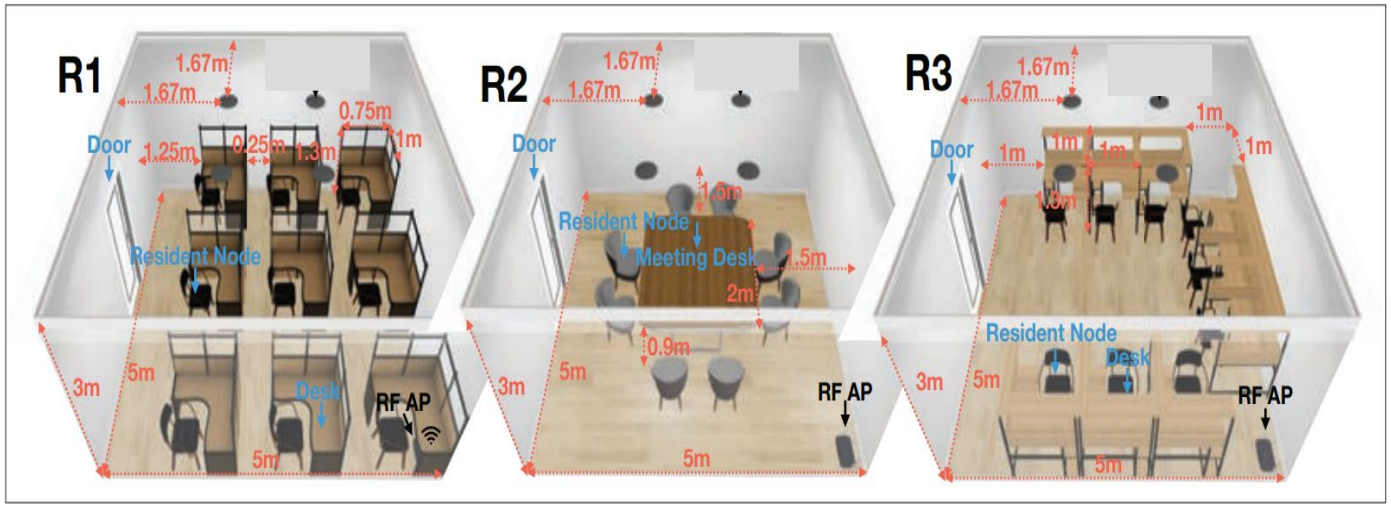


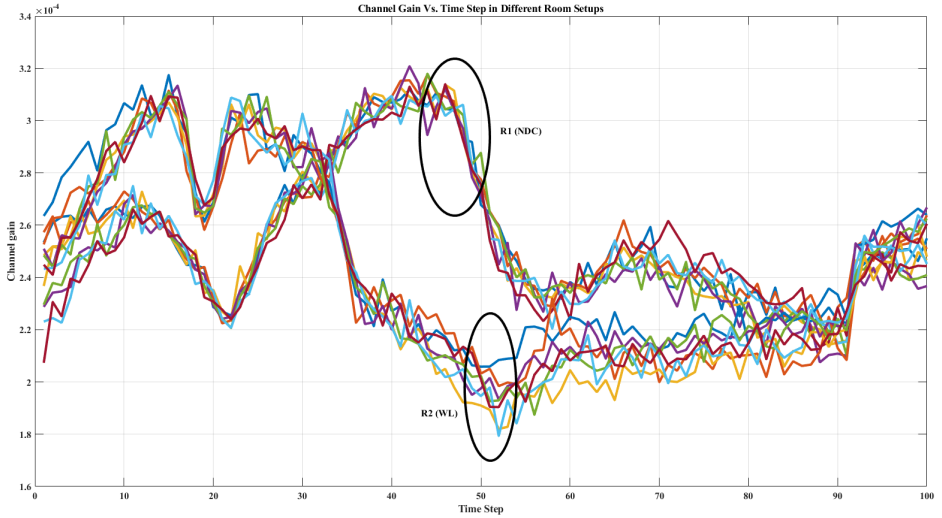


Using PhyPhox: records on UE orientation and measured spots (not complete trajectories)

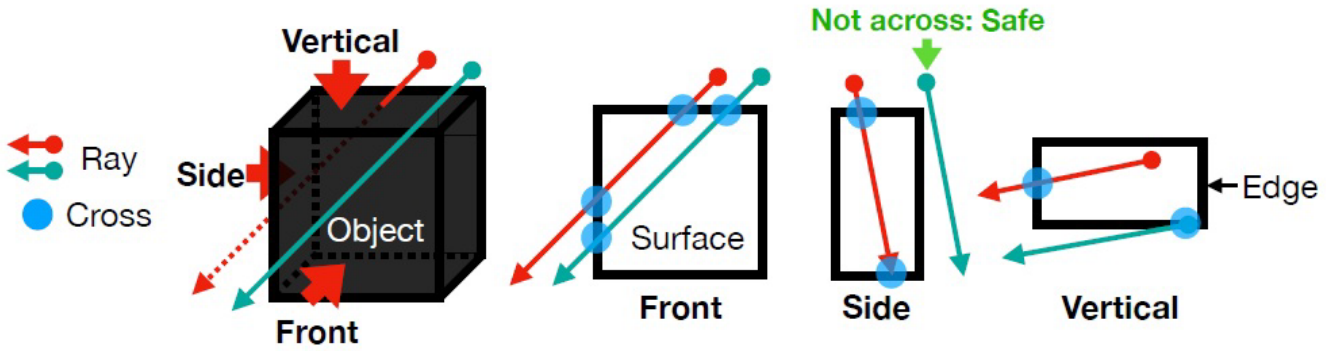
Dataset Generation (3/3)

Preliminary Work:





Intersection of ray with surface ➔ blockage?



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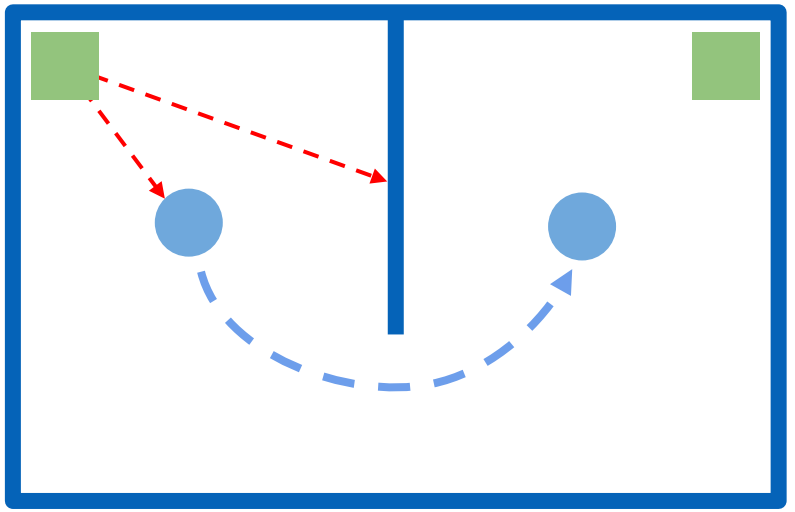
Prediction Models and Link Assignment (1/4)

- The short reach and high obstruction rate means that **handovers are frequent**
  - Any obstacle or even movement can put the user out of reach from the access point (AP)
- The common strategy is to handover to a new AP after the channel state deteriorates
  - However, this forces the user into bad communication while the handover is processed
  - This is even worse when multiple handovers are needed, which is common given the characteristics of WiGig

After the user moves, the AP cannot reach anymore due to the obstacle between the two



Handover will be done after the network notices that the user is out of reach

We need a solution better than reactive handovers, we need to proactively re-associate users before service worsens

Prediction Models and Link Assignment (2/4)

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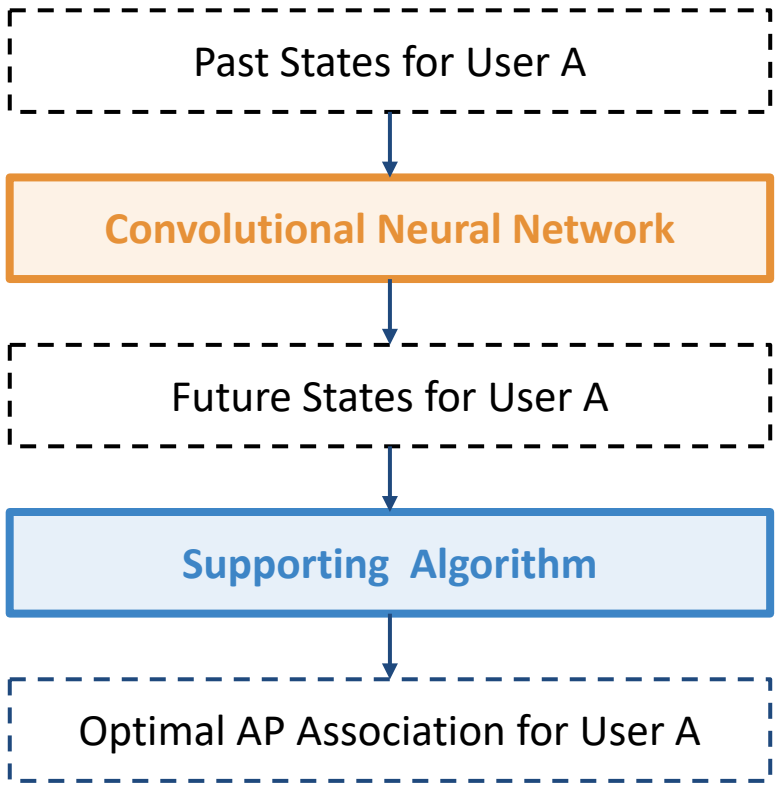
Preliminary Work:

- Use of a **Convolutional Neural Network (CNN)** to predict future channel state and traffic patterns
- Based on future network state, proactively perform handovers to keep stable connections with high quality signal
  - Proactive handovers greatly lowers the downtime of user connection when changing base stations
  - Stable connections greatly lowers the number of handovers needed
  - By predicting future state, service requirements can be properly satisfied



Prediction Models and Link Assignment (3/4)

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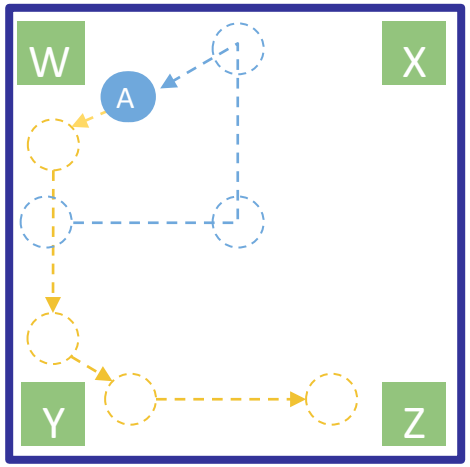
Preliminary Work:

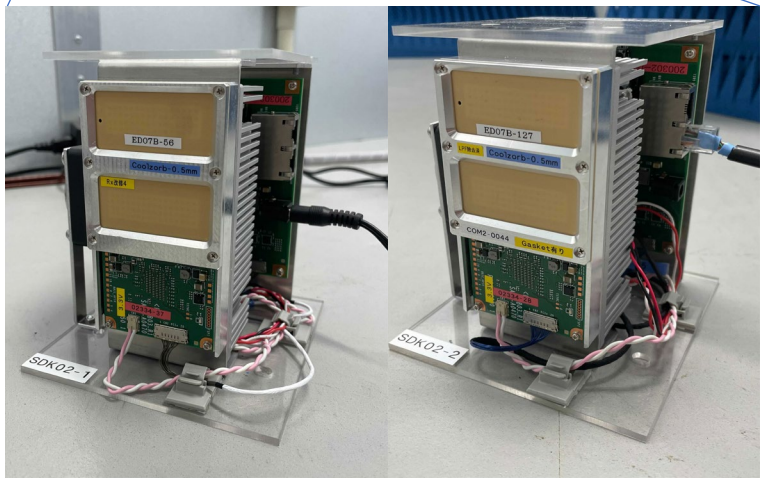
Current time slot: 4



Input (A)	1	2	3	4
W	-31	-37	-31	-24
X	-39	-34	-32	-38
Y	-32	-36	-41	-39
Z	-41	-35	-39	-44

CNN

Output (A)	5	6	7	8
W	-23	-36	-38	-44
X	-40	-44	-44	-37
Y	-37	-22	-21	-37
Z	-43	-39	-37	-22



WiGig TX WiGig RX

Prediction Models and Link Assignment (4/4)

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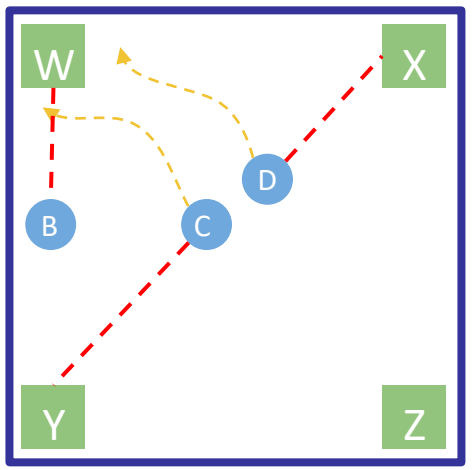
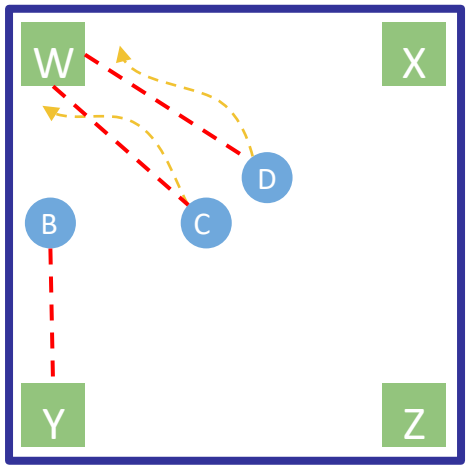
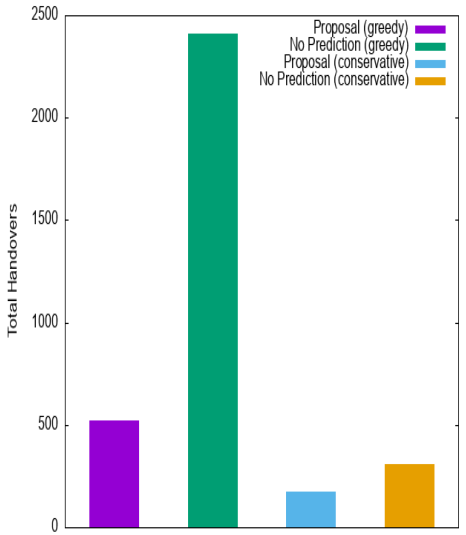
Preliminary Work:

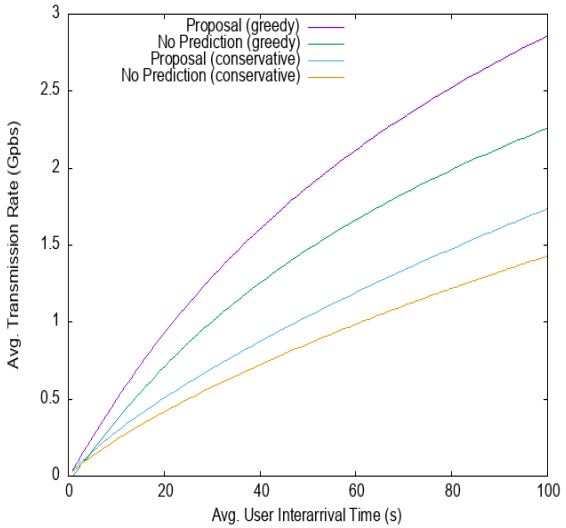
WITHOUT PREDICTION



WITH PREDICTION







Output(B)	5	6	7	8
W	-31	-31	-31	-31
X	-40	-40	-40	-40
Y	-31	-31	-31	-31
Z	-41	-41	-41	-41

Output(C)	5	6	7	8
W	-36	-32	-30	-27
X	-35	-36	-38	-39
Y	-34	-37	-37	-38
Z	-37	-39	-42	-44

Output(D)	5	6	7	8
W	-35	-33	-31	-28
X	-34	-35	-37	-38
Y	-37	-38	-38	-39
Z	-36	-39	-41	-44

Algorithm for Deciding Association

B→Y **C→W** **D→W**

T. Rodrigues, S. Verma, Y. Kawamoto, **N. Kato, M. Fouda, and M. Ismail**, "Smart handover with predicted user behavior using convolutional neural networks or WiGig systems," IEEE Network, Under Review.

Link Assignment Models (1/3)

Idaho State University

Preliminary Work:

- Conducted a review of the AI-based algorithms for optimizing the HO in future 5G NR and 6G networks.
- Data Types:
  - Visual Data
  - Wireless Data
- AI-based Techniques
  - AI-based Beam Selection
  - AI-based Base Station Selection

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Ahmed F. Ashour and Mostafa M. Fouda
(Idaho State University, USA)

the paper titled

AI-Based Approaches for Handover Optimization in 5G New Radio and 6G Wireless Networks

at The 2023 International Conference on Computer Science, Information Technology and Engineering
with theme "Digital Transformation Strategy in Facing the VUCA and TUNA Era"
on 16 February 2023 in Jakarta, Indonesia

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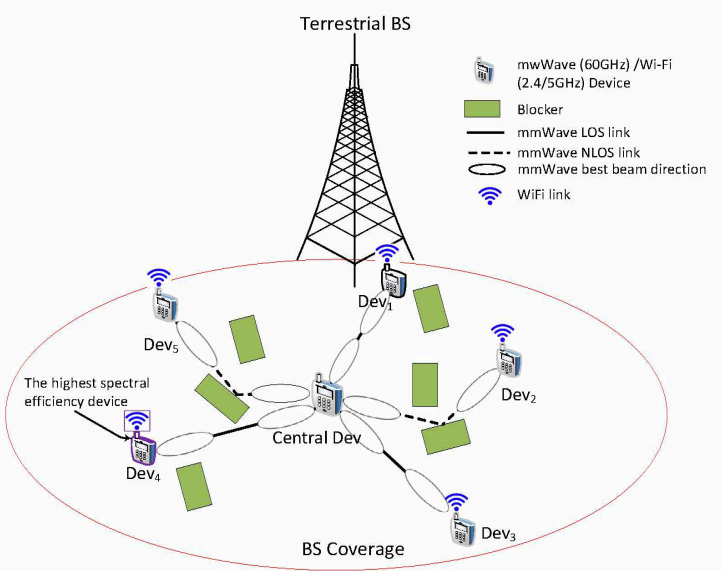
Ahmed F. Ashour and **Mostafa M. Fouda**, "AI-Based Approaches for Handover Optimization in 5G New Radio and 6G Wireless Networks," *Proc. of the 2023 International Conference on Computer Science, Information Technology and Engineering (ICCoSITE'23)*, Feb. 16–17, 2023.

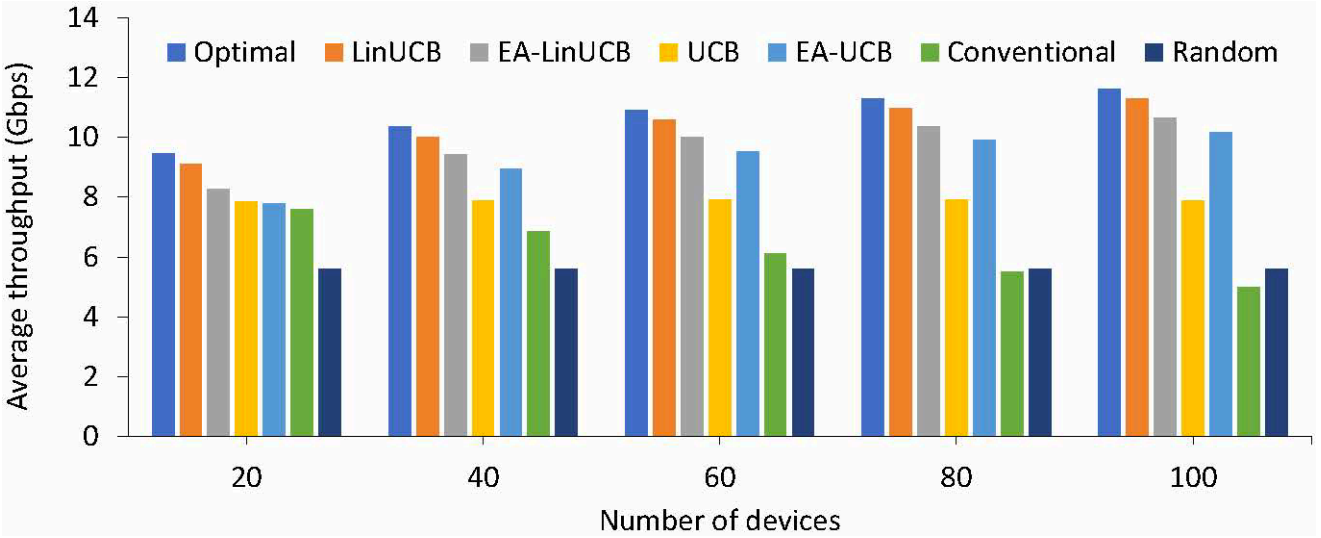
Link Assignment Models (2/3)

Idaho State University

Preliminary Work:

Scenario 1: Optimal Policy Selection in mmWave-enabled D2D Neighbor Discovery Service (NDS)





Average throughput comparison of MAB algorithms in mmWave NDS at no blockage where LinUCB shows the best performance

UCB: Upper Confidence Bound
EA-UCB: Energy-Aware UCB
LinUCB: Linear UCB
EA-LinUCB: Energy-Aware LinUCB

Sherief Hashima, Zubair Md Fadlullah, **Mostafa M. Fouda**, Ehab Mahmoud Mohamed, Kohei Hatano, Basem M. ElHalawany, and Mohsen Guizani, "On Softwarization of Intelligence in 6G Networks for Ultra-Fast Optimal Policy Selection: Challenges and Opportunities," *IEEE Network*, in press, doi: 10.1109/MNET.103.2100587.

Link Assignment Models (3/3)

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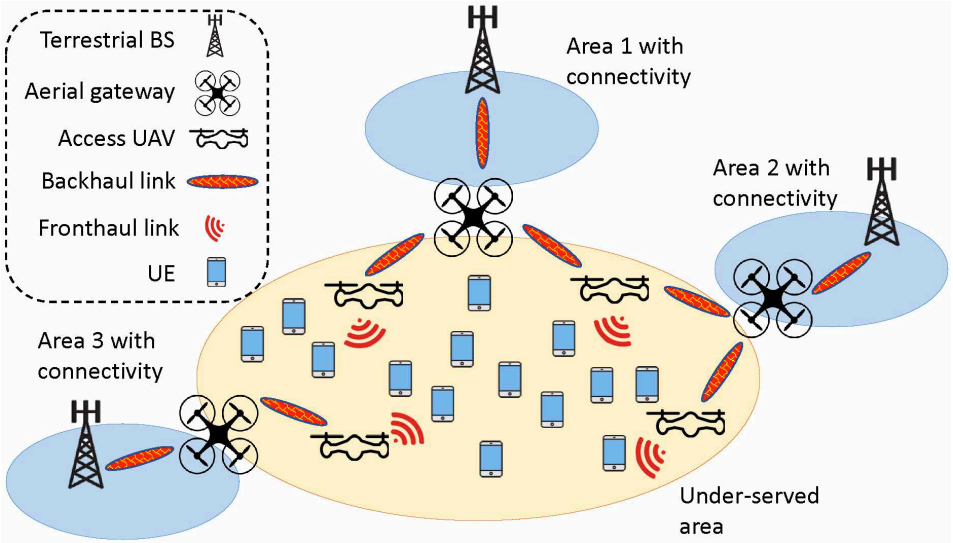
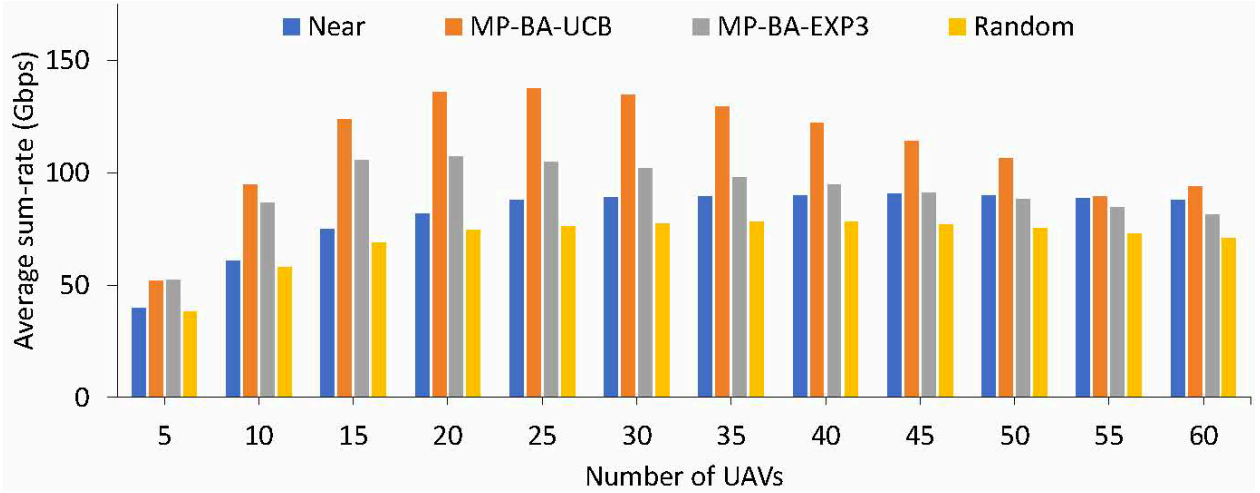
Preliminary Work:

Scenario 2: Aerial Gateway Selection for UAV-based Communication Network in an Under-served Area





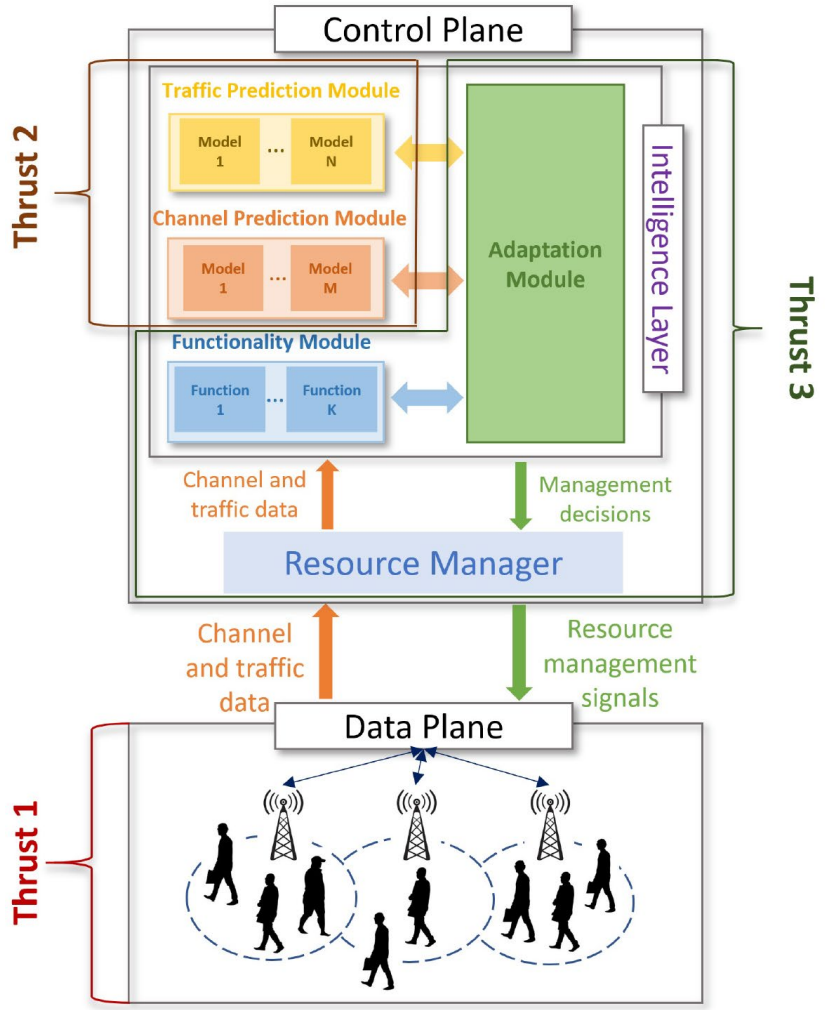
Average sum-rate for different numbers of access UAVs using 20 aerial gateways and 60° beamwidth where MP-BA-UCB shows the best performance

MP-BA-UCB: Multi-Player Battery-Aware Upper Confidence Bound
MP-BA-EXP3: Multi-Player Battery-Aware Exponential-weight algorithm (EXP3)

Sherief Hashima, Zubair Md Fadlullah, **Mostafa M. Fouda**, Ehab Mahmoud Mohamed, Kohei Hatano, Basem M. ElHalawany, and Mohsen Guizani, "On Softwarization of Intelligence in 6G Networks for Ultra-Fast Optimal Policy Selection: Challenges and Opportunities," *IEEE Network*, in press, doi: 10.1109/MNET.103.2100587.

Conclusions

- First in-person meeting – TNTech, Jan. 31st, 2023
- Generation of indoor WiGig channel dataset
- Prediction-based link assignment strategy in WiGig
- Dynamic policy selection for link assignment in heterogeneous WiGig networks



Future Work

- Integrating the mobility model developed at TNTech with the pro-active link assignment model developed at Tohoku University
- Validate channel data generated at TNTech using the WiGig testbed at Tohoku University
- Predcition-based link assignment based on channel and traffic data
- Introducing prediction models in the policy selection framework to be developed by ISU

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Thank You!