Geometry Aware Proactive Control of mmWave Communications

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Talk outline

1. Background: mmWave access networks
2. Problem: Human blockage
3. Geometry-aware Proactive control of mmWave networks
4. Prototype implementation
5. Proof of concept experiment
6. Conclusion
mmWave communications

It’s a key wireless band for next generation wireless access networks such as 5G cellular and IEEE 802.11ay WiGig.

There are lots of open issues in MAC and higher layers since its propagation characteristics are quite different from conventional microwave communications.
Human blockage in mmWave access networks

mmWave network testbed using IEEE 802.11ad devices
Human blockage in mmWave access networks

IEEE 802.11ad mmWave Access Point

IEEE 802.11ad mmWave stations
Human blockage in mmWave access networks
Human blockage in mmWave access networks
Human blockage

When line of sight (LOS) path is blocked by pedestrians, the signal strength sharply decreases. -> Quality of service is largely degraded.

Experimental result using IEEE 802.11ad devices
Possible solutions

Adaptive beamforming, handover

Dynamically adjusting beam angle and handovering could recover a link quality degraded by blockage.

However, these operations are conducted when link quality degradation is detected. Short term but huge link quality degradation can not be avoided.
Geometry aware Proactive Control of mmWave NWs

Capturing **geometry** of environment and **mobility** of users and obstacles by sensors like optical camera and LIDAR

**KEY IDEA**

Predictively controlling mmWave communications based on geometry and mobility

Example:
- Proactive handover,
- Beam switching,
- Sleep & Wakeup control
Prediction based proactive handover

Avoiding throughput degradation caused by human blockage

From camera images, mobility of obstacles are estimated and blockage timing when LOS path will blocked is predicted.

AP handover is conducted before pedestrian blocks LOS path.

Stable and high throughput
Research Challenges

How we extract useful information from images
- Motion capture based human blockage prediction [i]
- Machine learning based approach [ii]

How we use the information
- Proactive traffic control [iii]
- Proactive AP handover [i]

We implemented a prototype of Proactive AP handover with motion capture based human blockage prediction.

Proactive handover system model

- **Camera** captures images of communication area.
- **Prediction filter** analyzes the images and predicts future human blockage.
- **Controller** schedules handover timing so that handover is conducted before human blockage occurs.
Prototype Implementation

- RGB-D camera (Microsoft Kinect)
- Controller/Prediction filter
- IEEE 802.11ad mmWave AP (DELL Docking station)
- IEEE 802.11ad mmWave STA (DELL Laptop)
- A virtual mmWave station
Prototype system

- Functions of the prediction filter and controller are implemented on a laptop.
- A cluster of laptops serve as one virtual mmWave STA so that STA can connect APs immediately without re-association.
Human blockage prediction

Prediction filter predicts a time left until a pedestrian blocks LOS path based on
• location of LOS path estimated from location of APs and STAs
• location of pedestrian obtained from Camera
• velocity and direction of pedestrian estimated on the basis of the interframe motion of a pedestrian

Position of a pedestrian is estimated using the player recognition of Kinect.

Two solid lines represent LOS paths 1 and 2.
Scenario of experiments

Proactive handover
Handover is activated when the predicted time left until a pedestrian blocks the currently used path is smaller than 1 s.

Reactive handover
Handover is activated when the large throughput degradation is detected, i.e. when measured throughput is less than 300 Mbit/s.

During each measurement, a pedestrian blocks both paths twice. In each blockage, a LOS path is blocked for 10 s.

<table>
<thead>
<tr>
<th>Channels</th>
<th>60.48 and 62.64 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wired network</td>
<td>1000BASE-T Gigabit Ethernet</td>
</tr>
<tr>
<td>PHY rate</td>
<td>385-4620 Mbit/s</td>
</tr>
<tr>
<td>Measurement time</td>
<td>50 s</td>
</tr>
</tbody>
</table>
Experimental results (1/3)

Reactive handover  
which conducts handover when measured throughput decreases to be less than 300 Mbit/s.

Proactive handover  
which conducts handover when the predicted time left until a pedestrian blocks the currently used path is smaller than 1 s.
Experimental results (2/3)

Reactive handover
Large throughput degradation still exists.

Proactive handover reduces the low throughput periods.
Experimental results (3/3)

The diagram shows the cumulative distribution function of throughput for two schemes: Proactive and Reactive. The y-axis represents Cumulative distribution function, ranging from 0 to 1. The x-axis represents Throughput (Mbit/s), ranging from 0 to 600. The graph compares the performance of the two schemes, with the Proactive scheme represented by red and the Reactive scheme by blue. At a throughput of 300 Mbit/s, the Proactive scheme shows a cumulative distribution of 15%, while the Reactive scheme shows 3%.
Conclusion

Geometry Aware Proactive mmWave NW Control

• Camera image-based mmWave link quality prediction
• Prediction-based mmWave communication control

Proof of concept Experiments

Proactive handover works
Thank you.

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Work in progress: supervised learning based quantitative link quality prediction from depth camera images

Future link quality such as RSSI and throughput among APs and STAs enables fine grained scheduling.

Machine learning is expected to predict accurate link quality from images by using measured link quality as training dataset and learning relationships between link qualities and depth-images.

This work is submitted to VTC-spring.