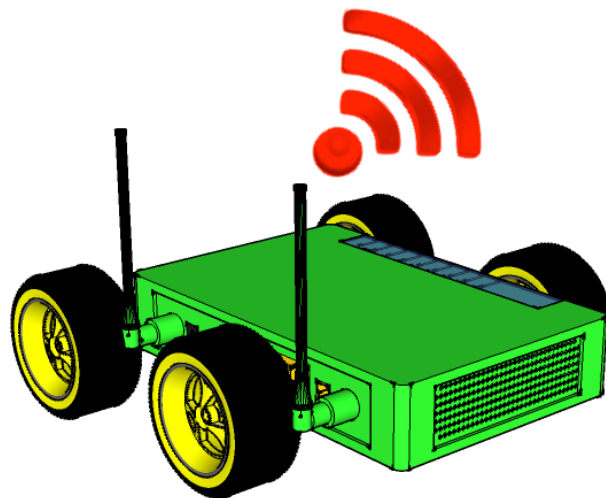


Infrastructure Mobility: A What-If Analysis



Mahanth Gowda



Nirupam Roy



Romit Roy Choudhury



Wireless Network Capacity

Revolutionary work in the last 30 years

Beamforming, MIMO, power-control, channel assignment, coding ...

Wireless Network Capacity

Revolutionary work in the last 30 years

Beamforming, MIMO, power-control, channel assignment, coding ...

Capacity is reaching Shannon's limit, but the demand
is still increasing

Wireless Network Capacity

Growing agreement in the community that we have reached saturation at the PHY Layer ...

Wireless Network Capacity

Growing agreement in the community that we have reached saturation at the PHY Layer ...

Next jump perhaps from new networking architectures.

Static Infrastructure, Mobile Clients



Static Infrastructure, Mobile Clients



Static Infrastructure, Mobile Clients



What if Infrastructure is Mobile



What if Infrastructure is Mobile



What if Infrastructure is Mobile



Regimes of Infrastructure Mobility



Mobility Range

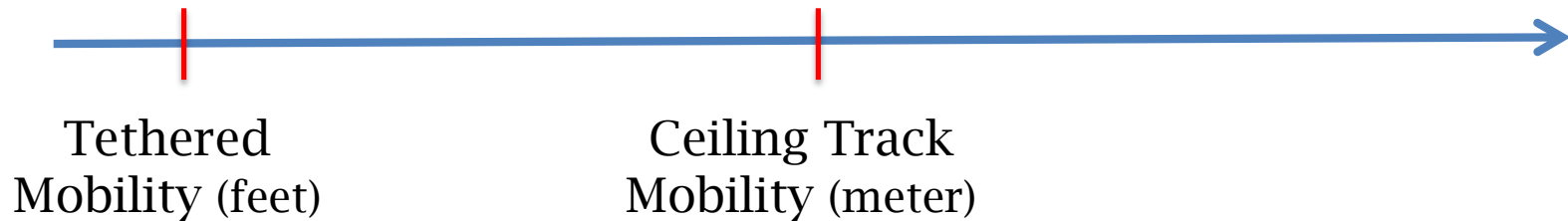
Regimes of Infrastructure Mobility



Tethered
Mobility (feet)

Mobility Range

Regimes of Infrastructure Mobility



Mobility Range

Regimes of Infrastructure Mobility



Tethered
Mobility (feet)

Ceiling Track
Mobility (meter)

Cell Tower
Relays (km)

Mobility Range

Regimes of Infrastructure Mobility



Tethered
Mobility (feet)

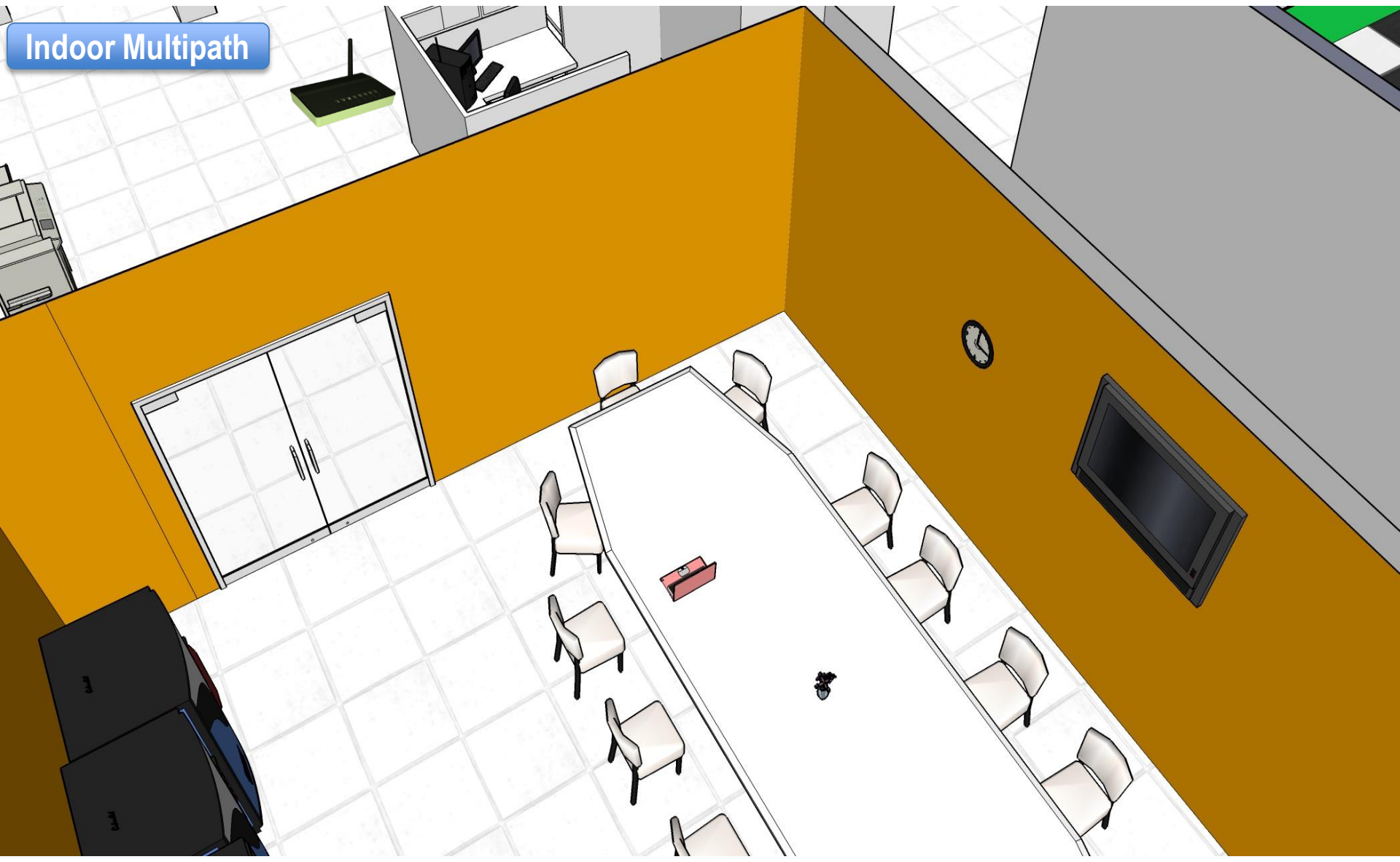
Ceiling Track
Mobility (meter)

Cell Tower
Relays (km)

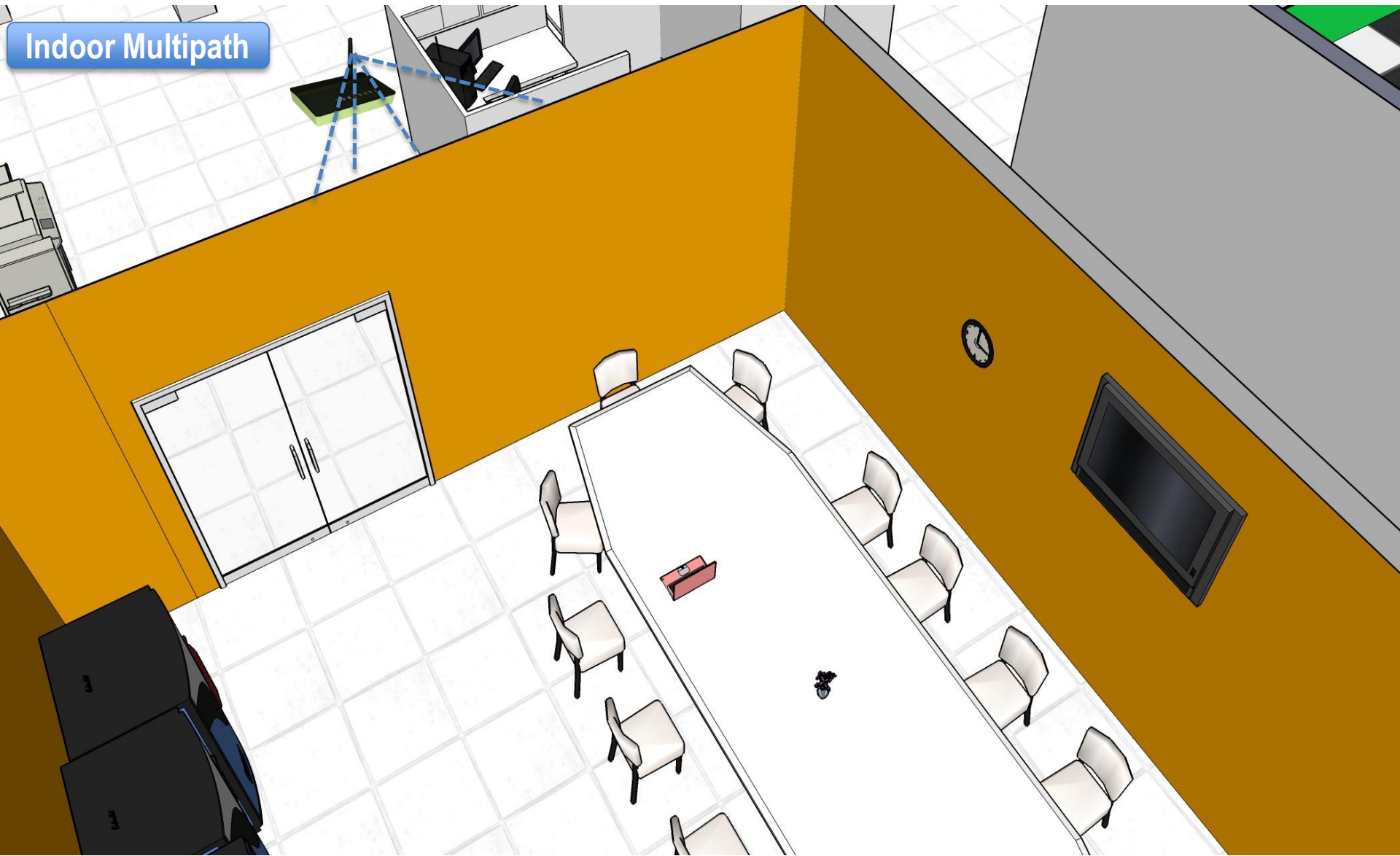
Mobility Range

Three main
sources of gains

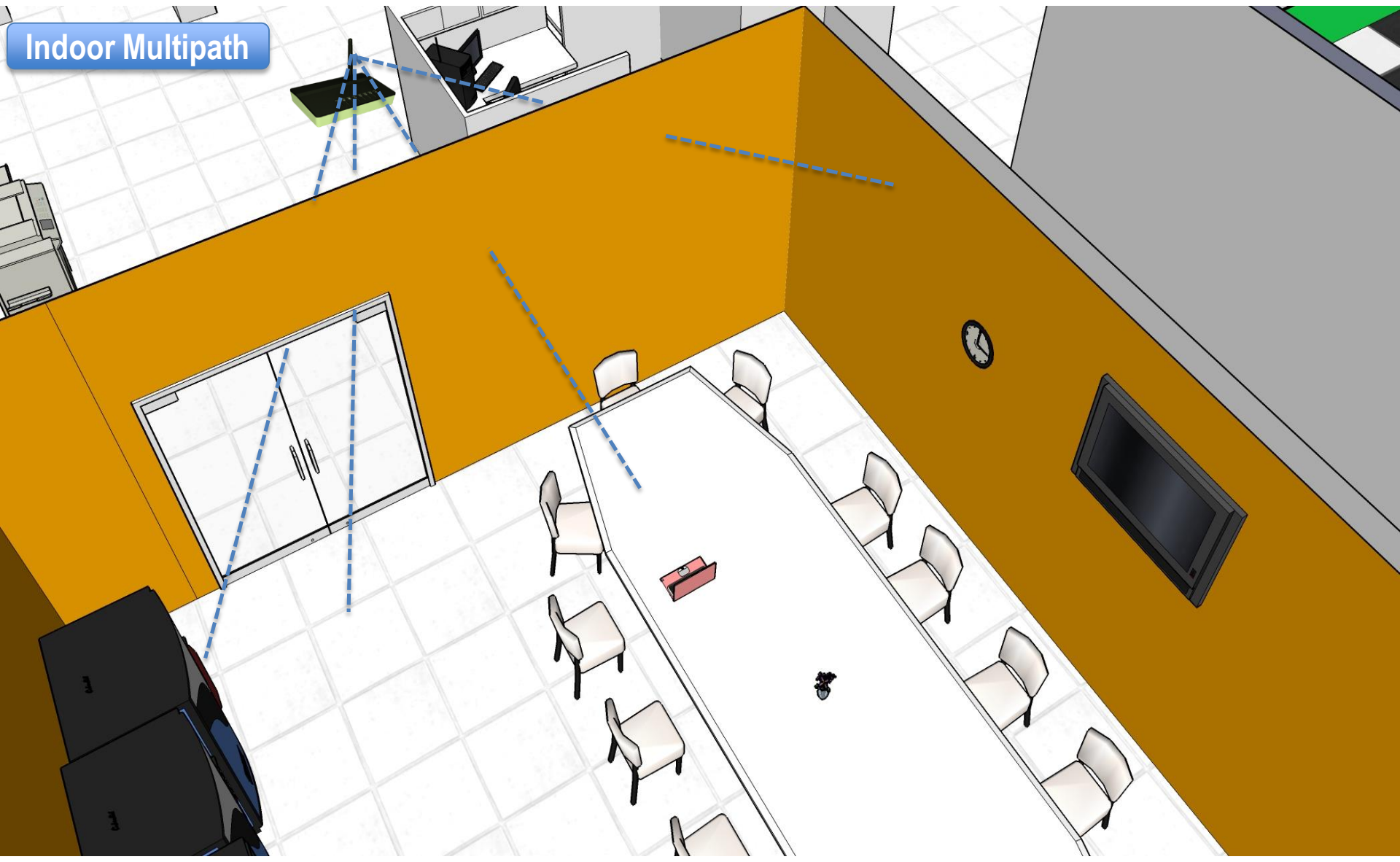
Indoor Multipath



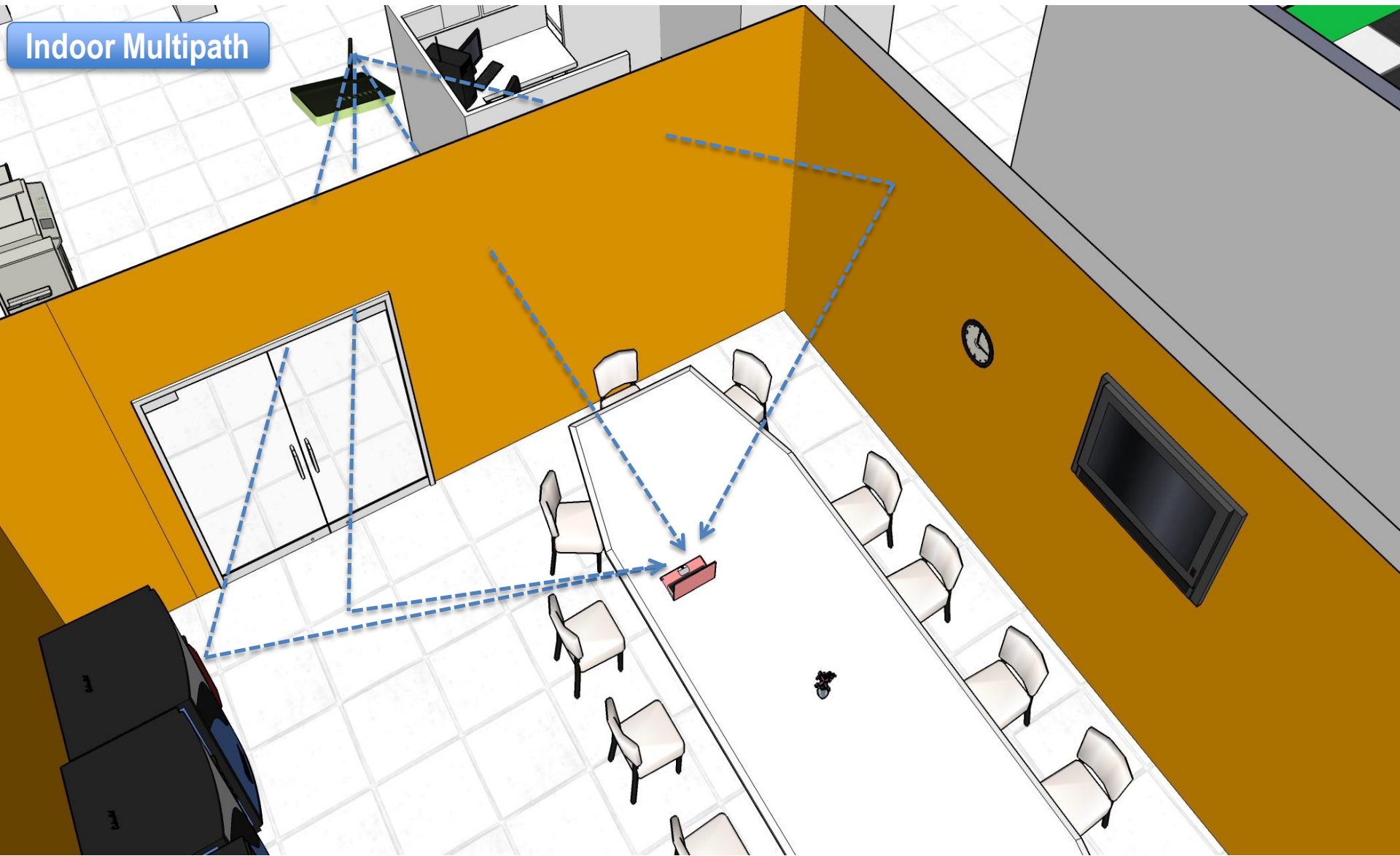
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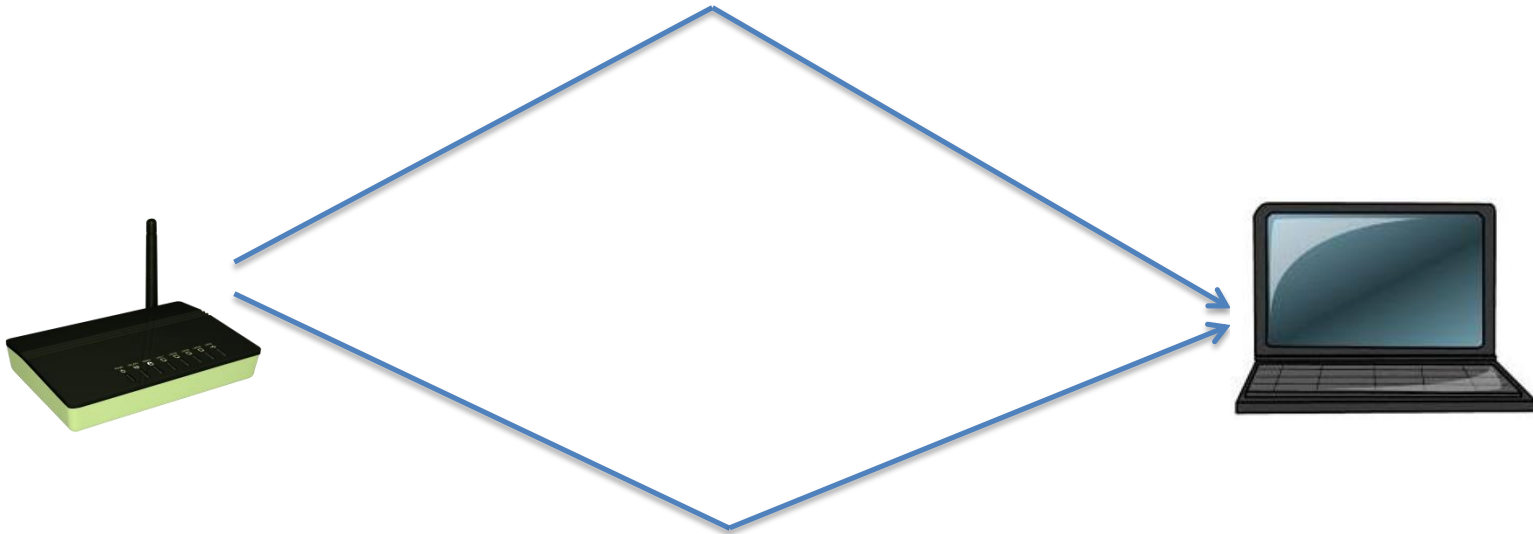
Indoor Multipath



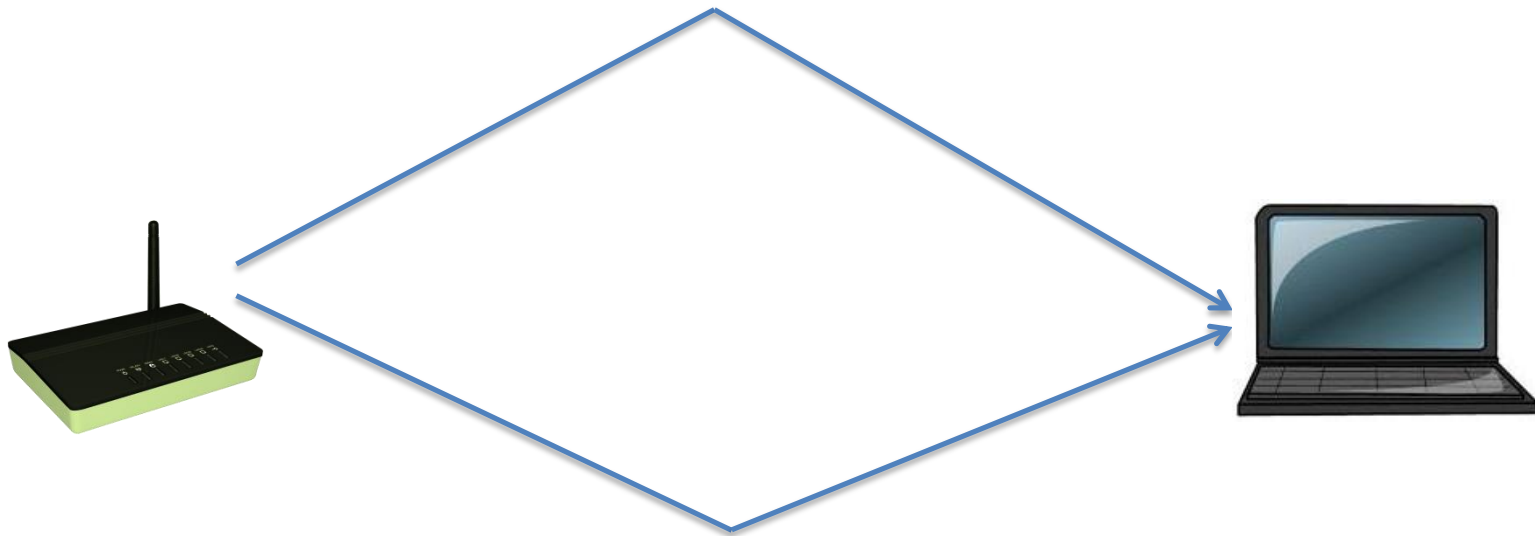
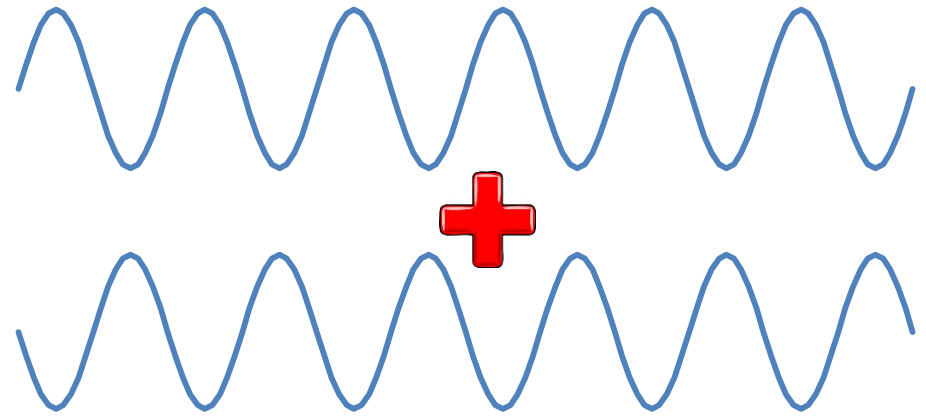
Multipath can Add up Destructively



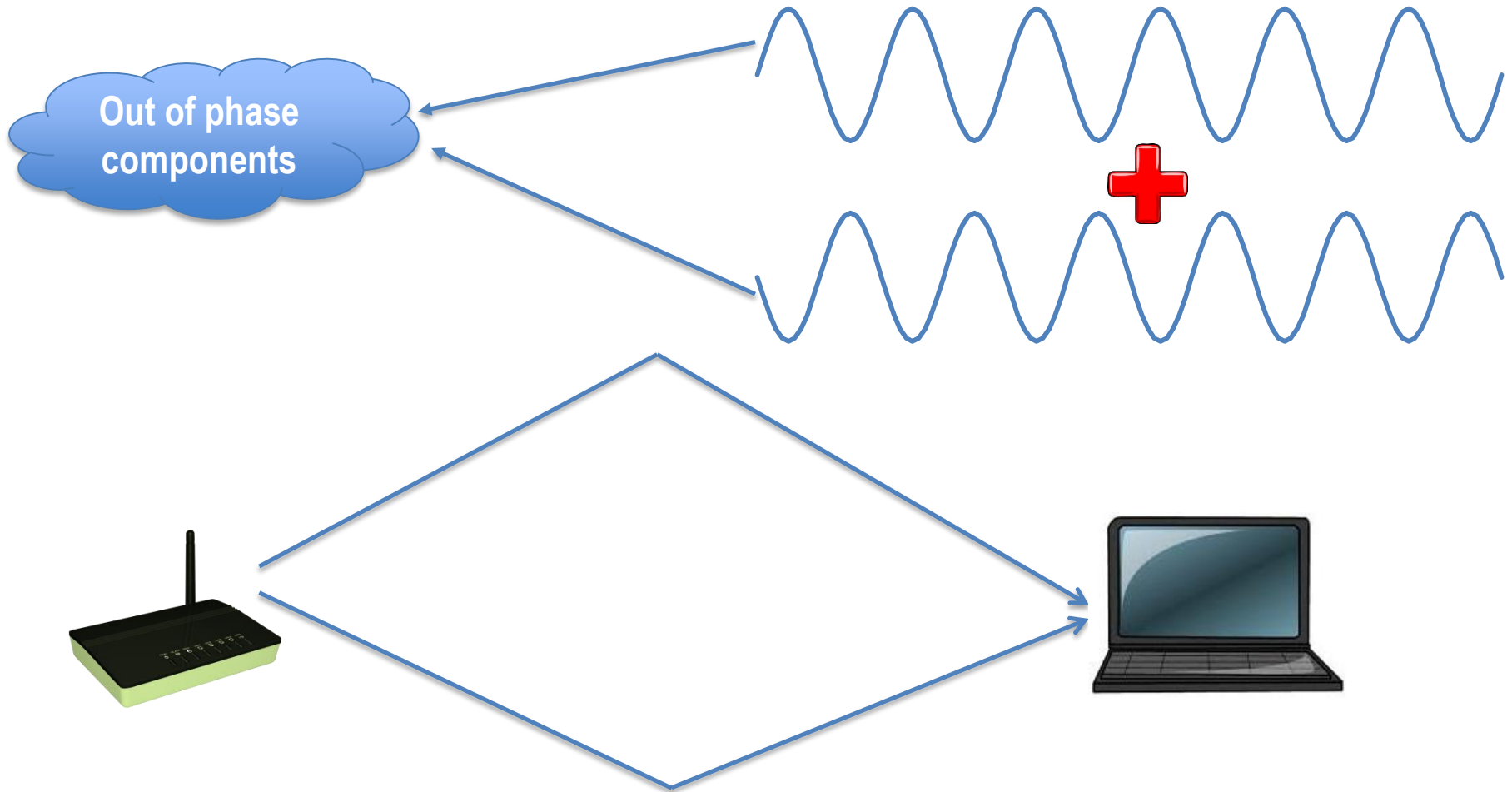
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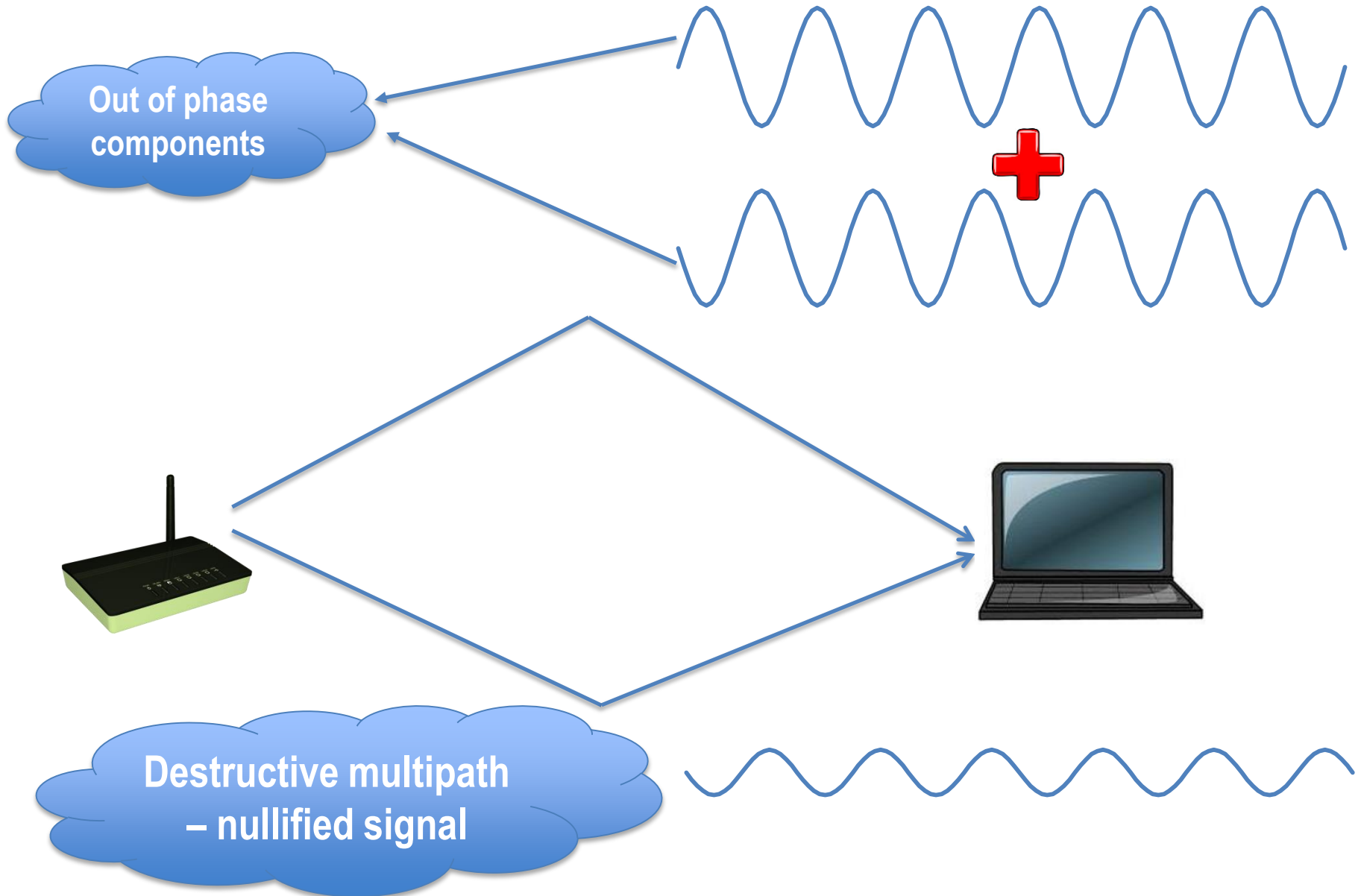
Multipath can Add up Destructively



Multipath can Add up Destructively



Multipath can Add up Destructively



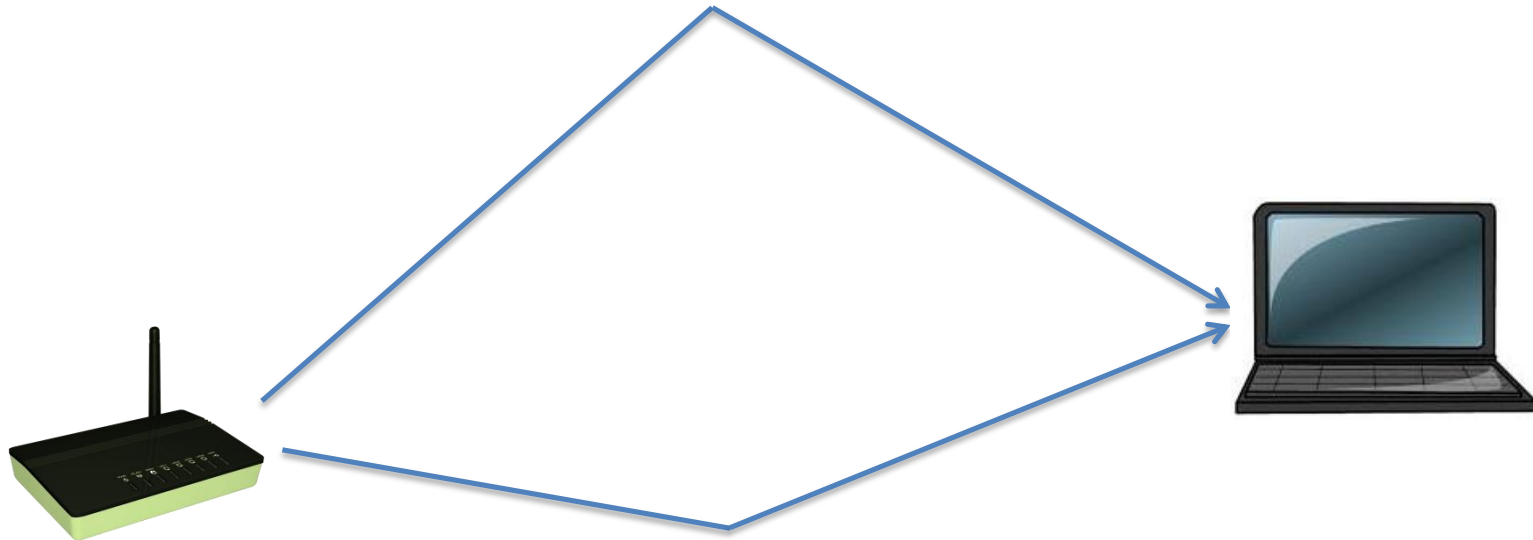
Small Mobility Facilitates Constructive Multipath



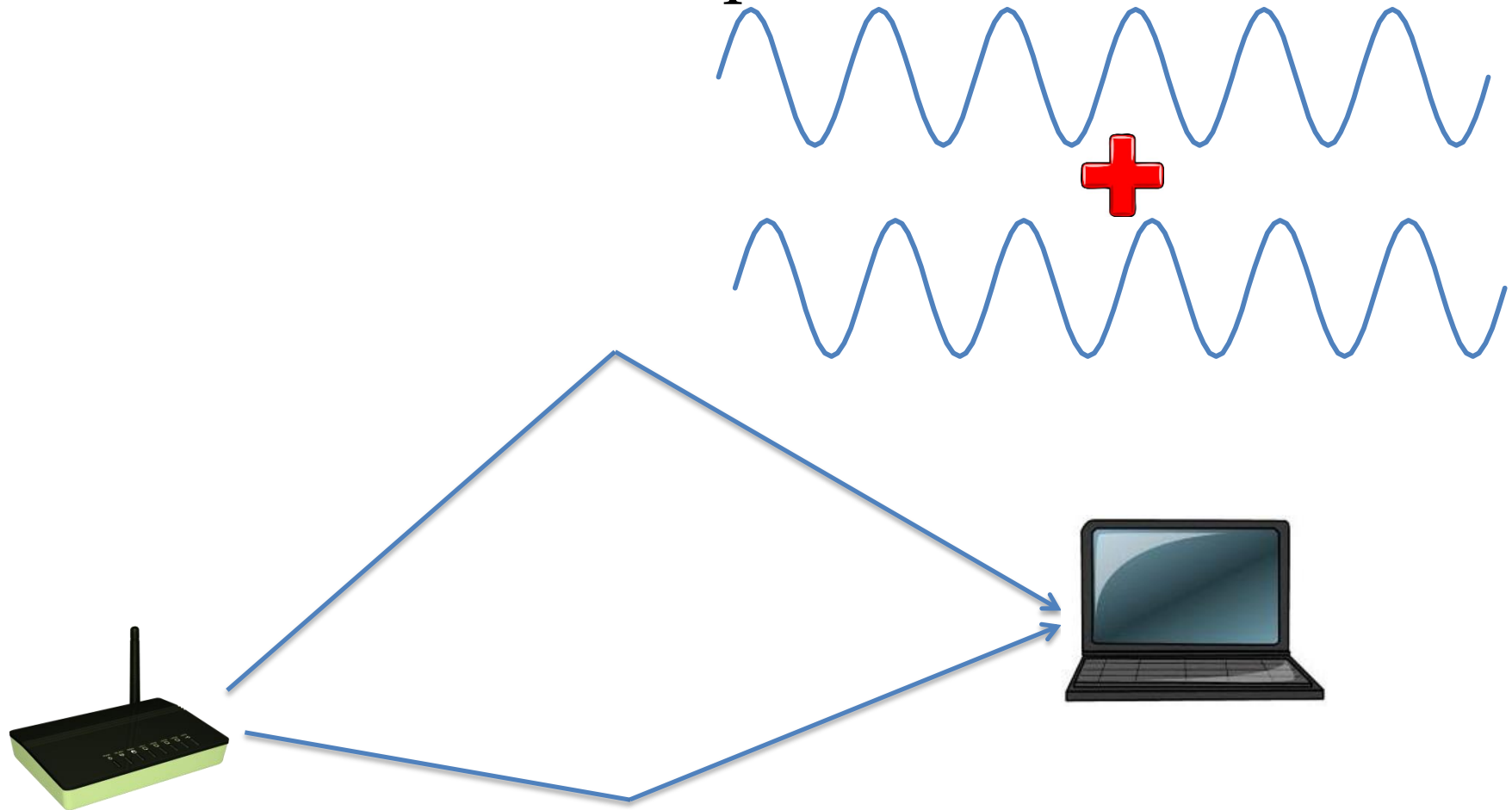
Small Mobility Facilitates Constructive Multipath



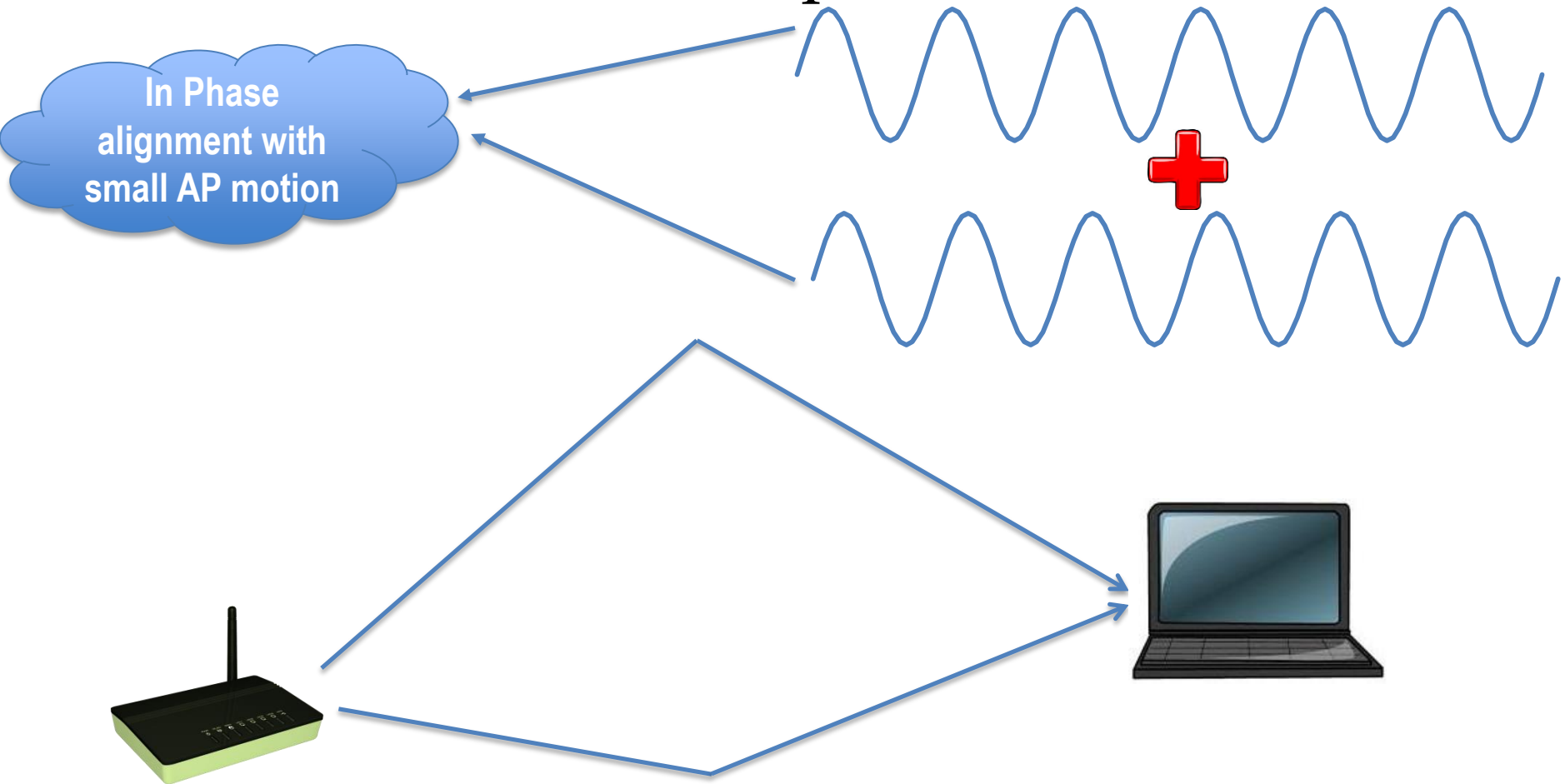
Small Mobility Facilitates Constructive Multipath



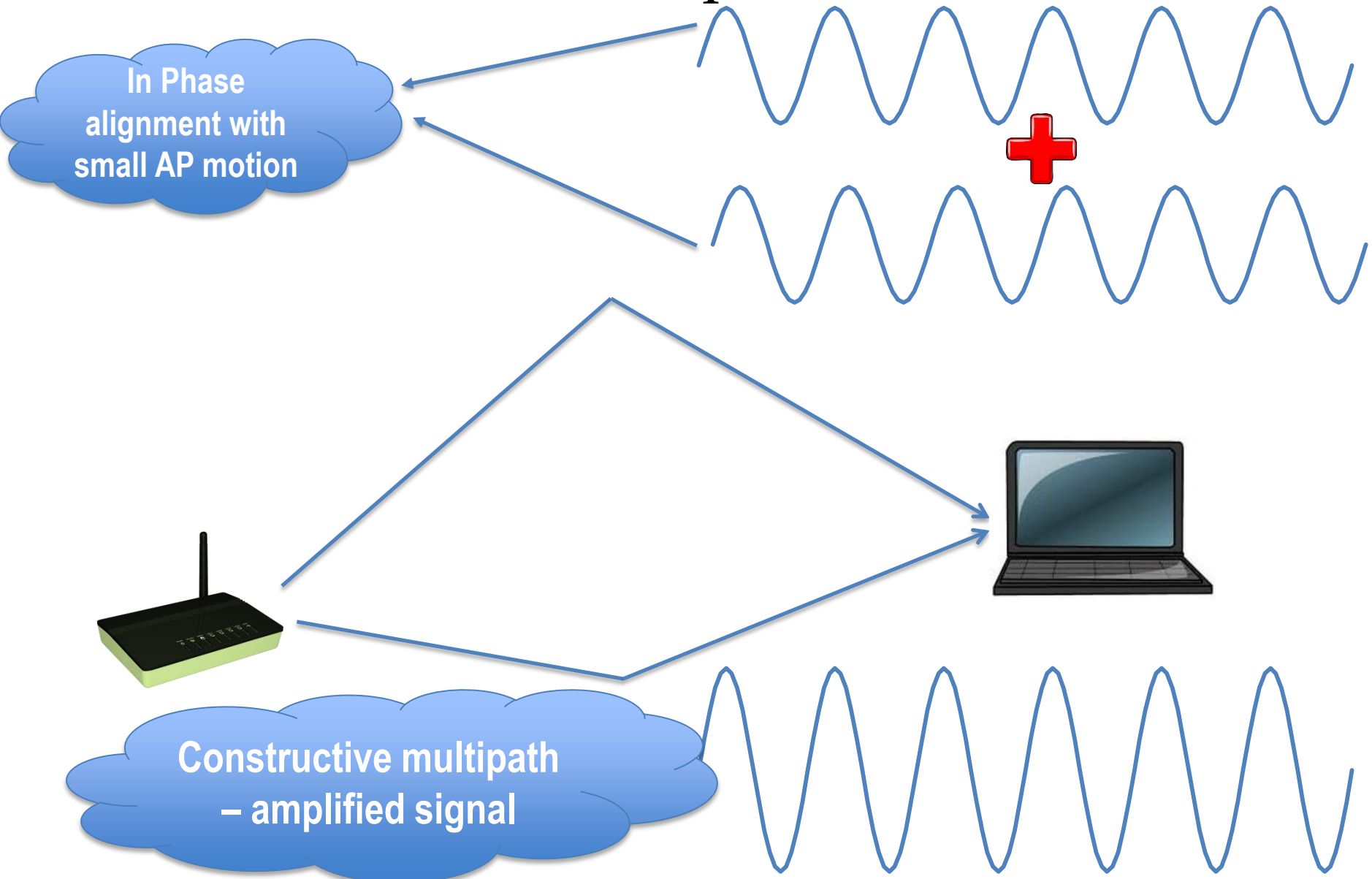
Small Mobility Facilitates Constructive Multipath



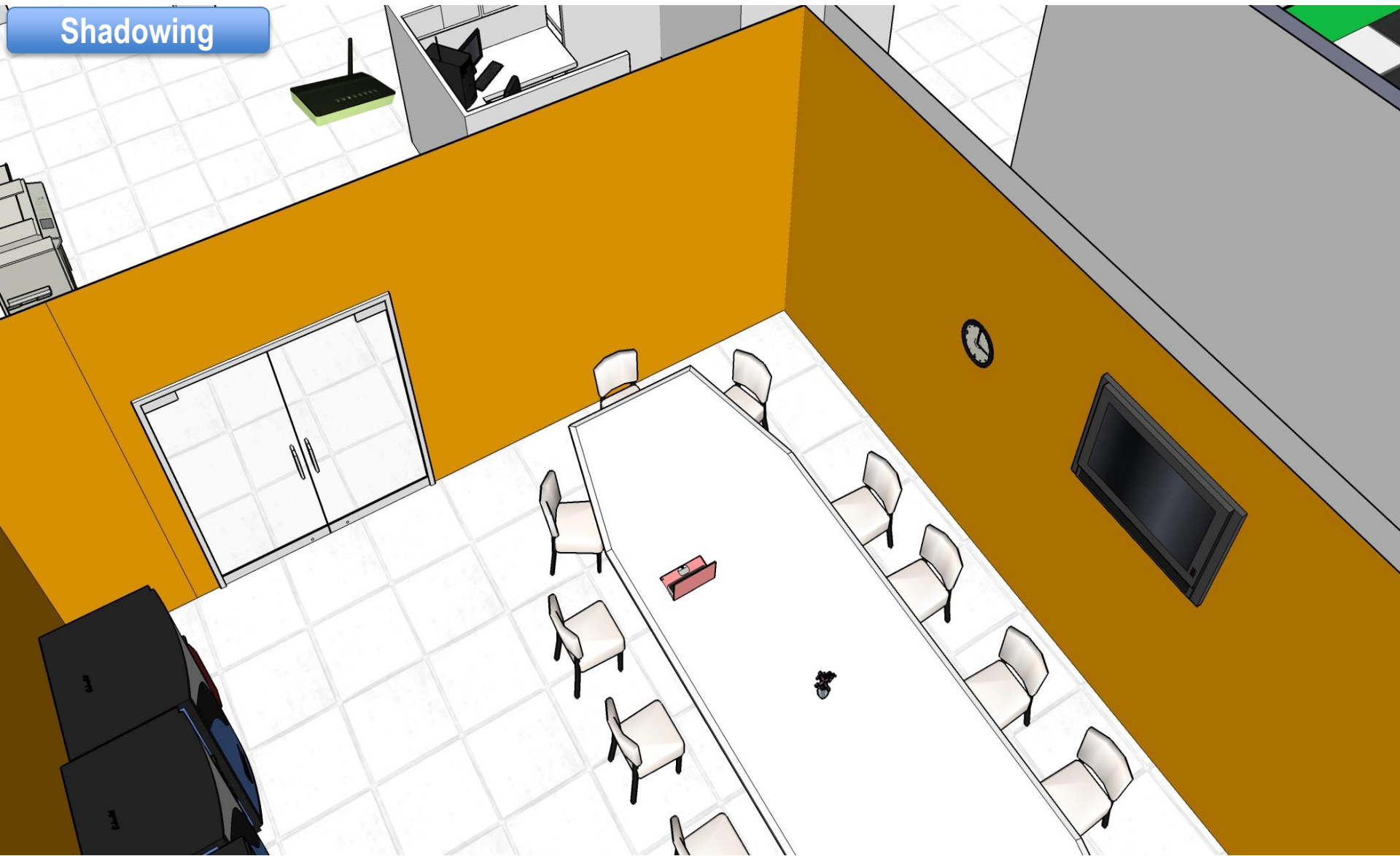
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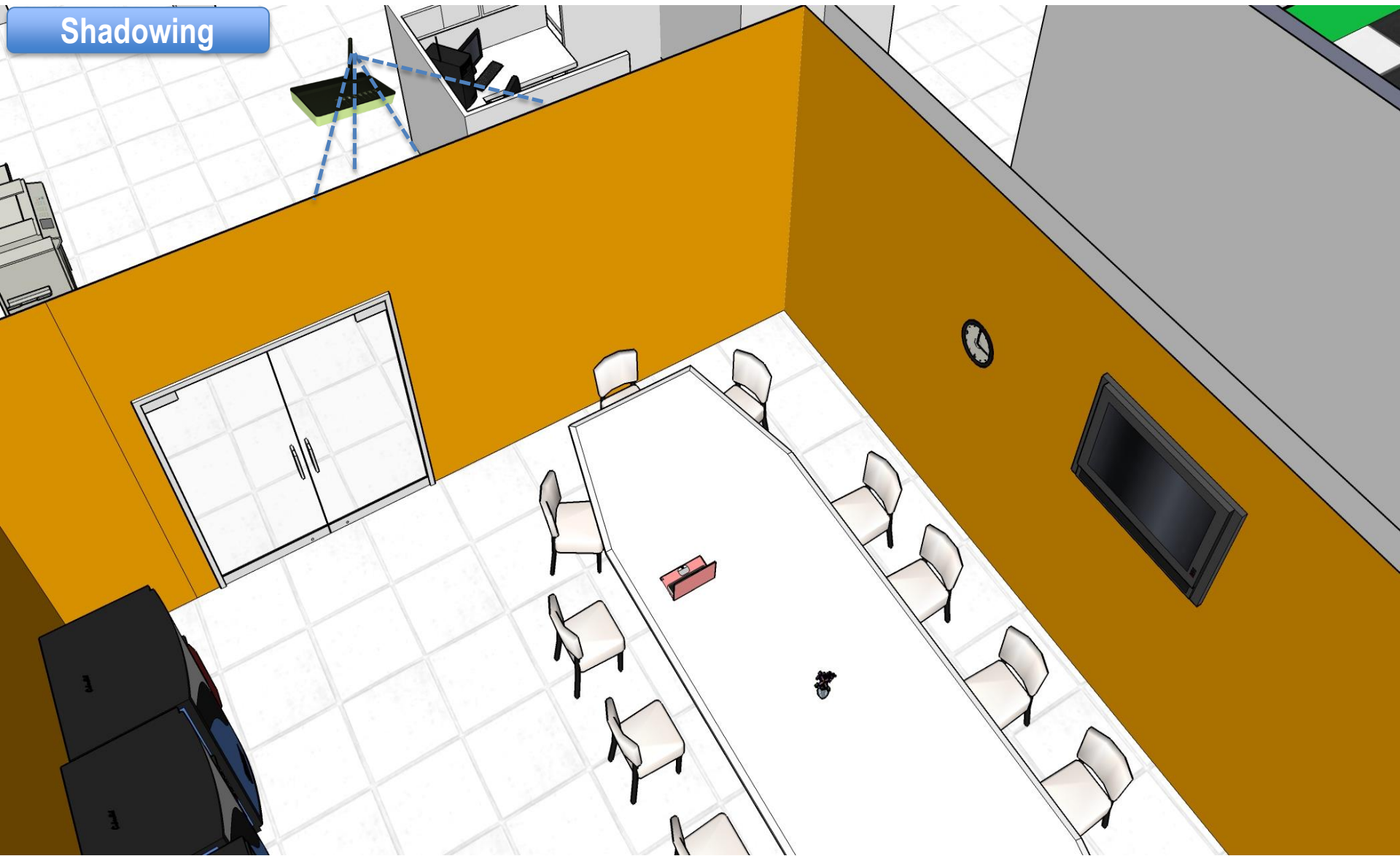
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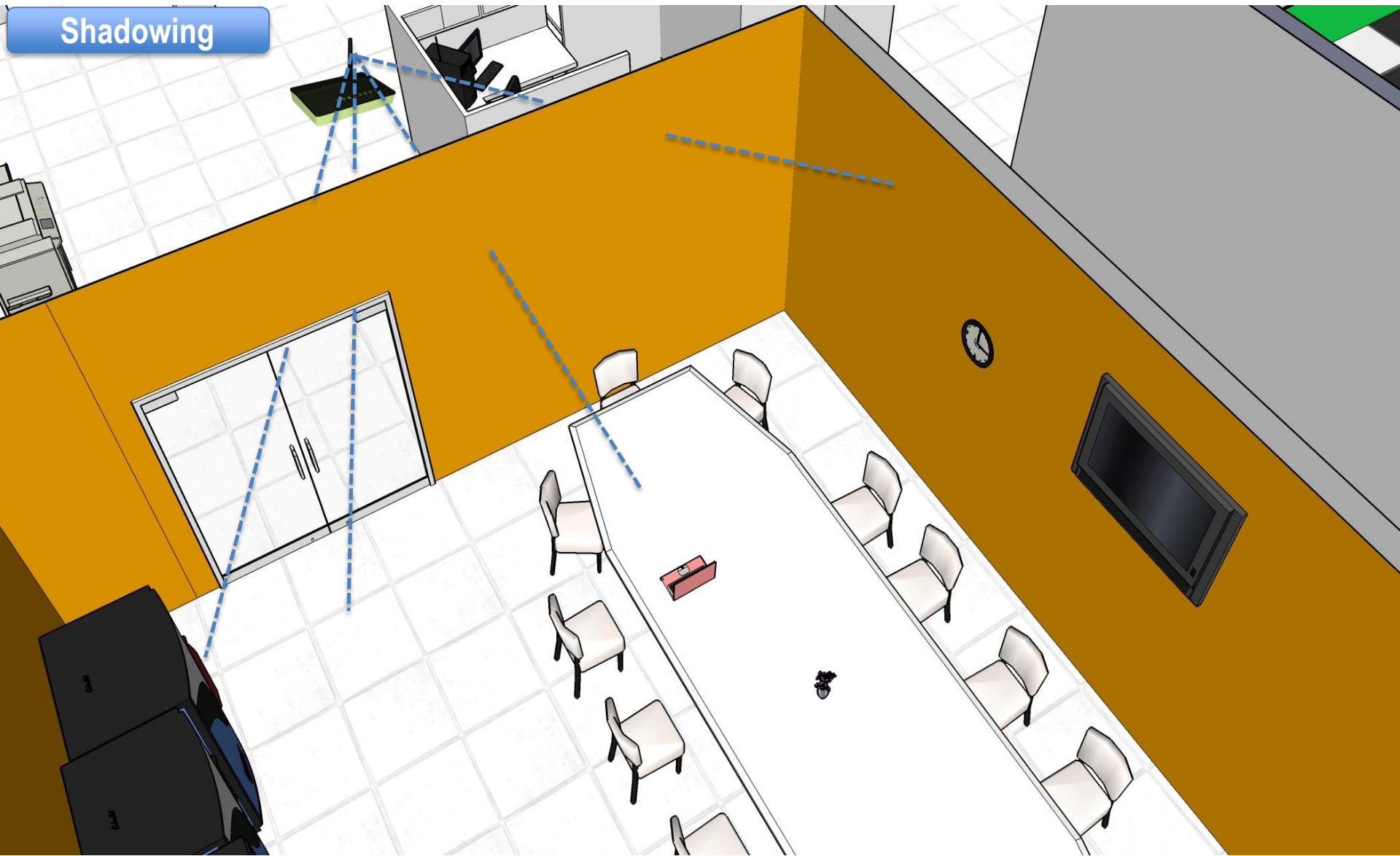
Shadowing



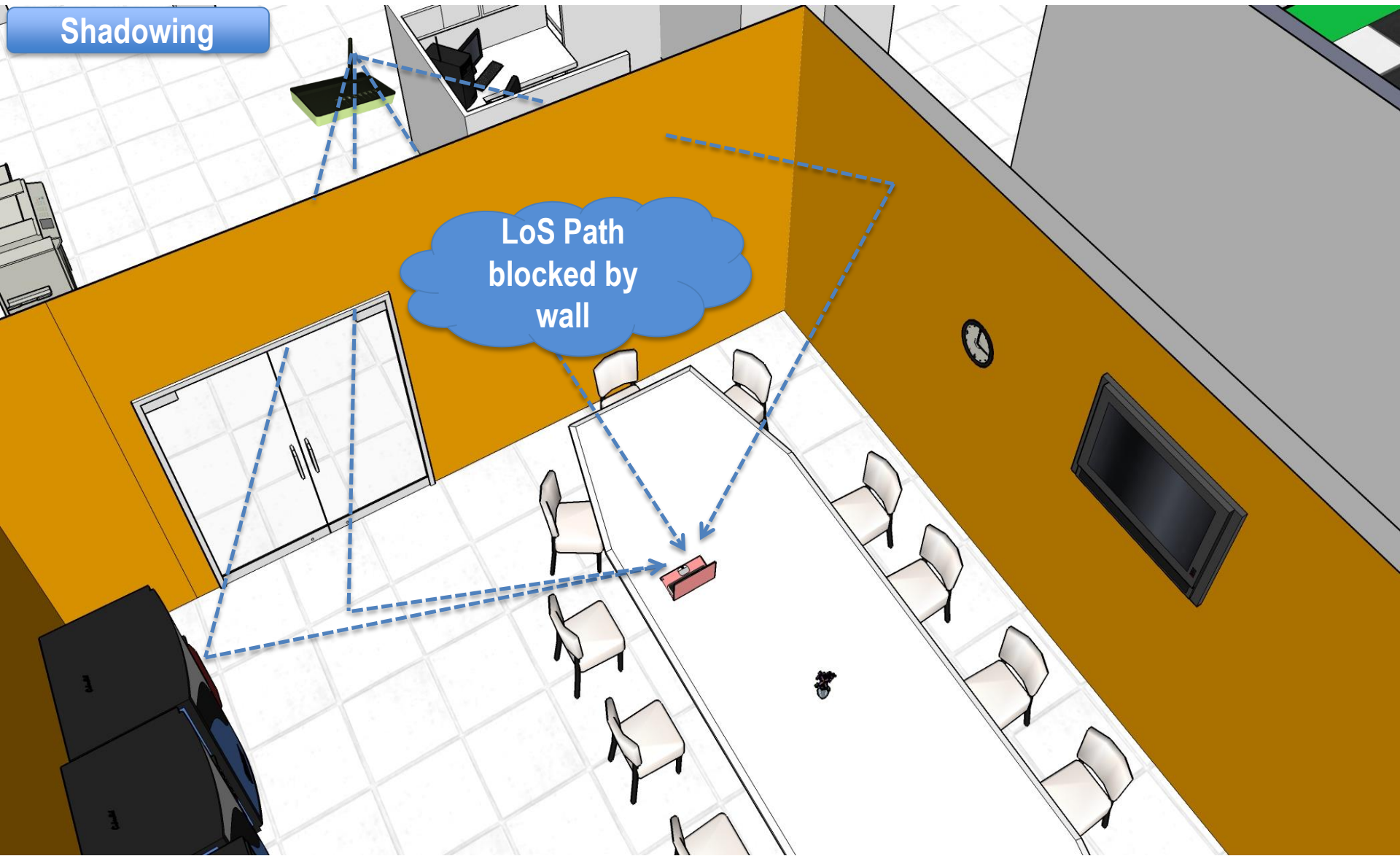
Shadowing



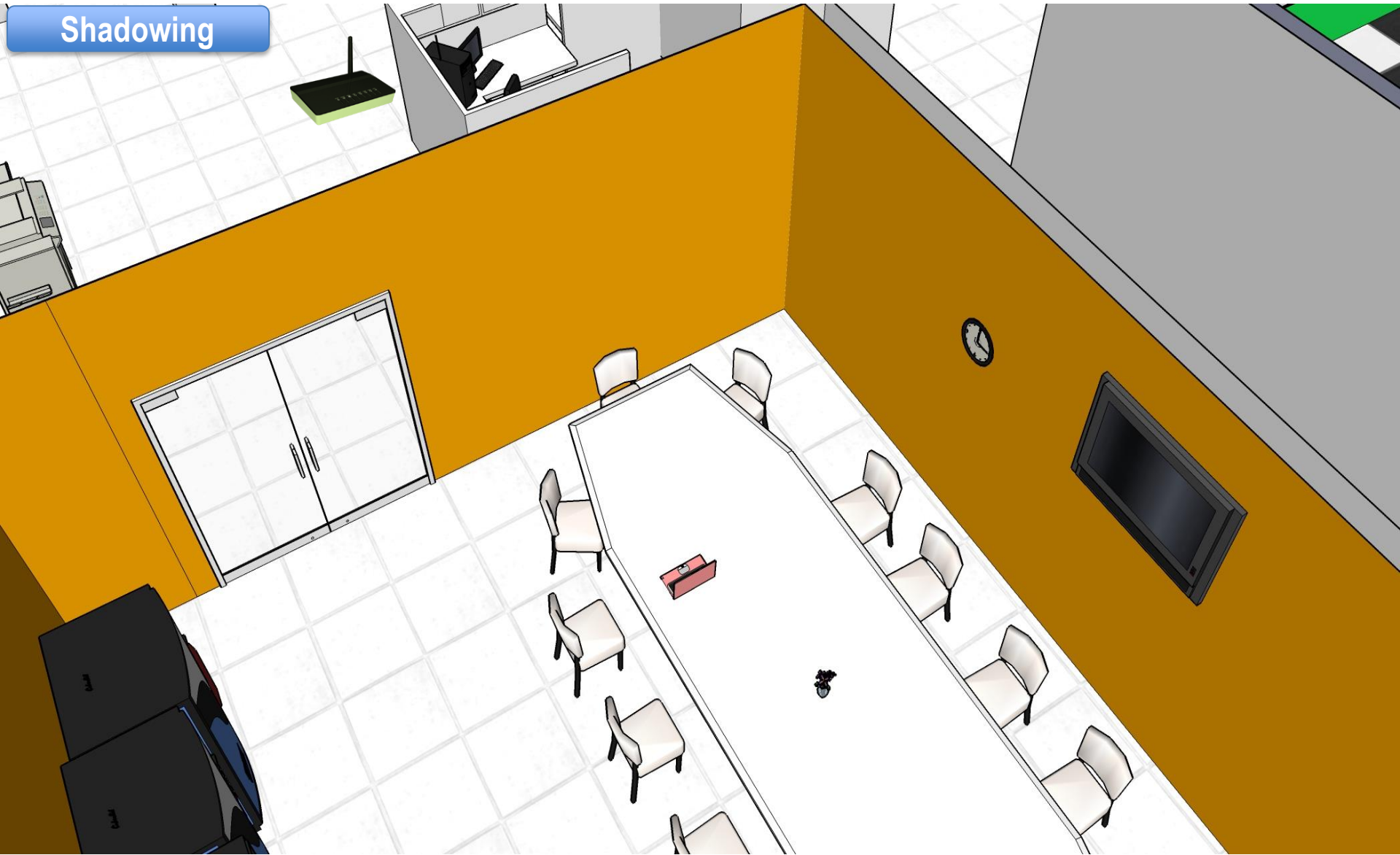
Shadowing



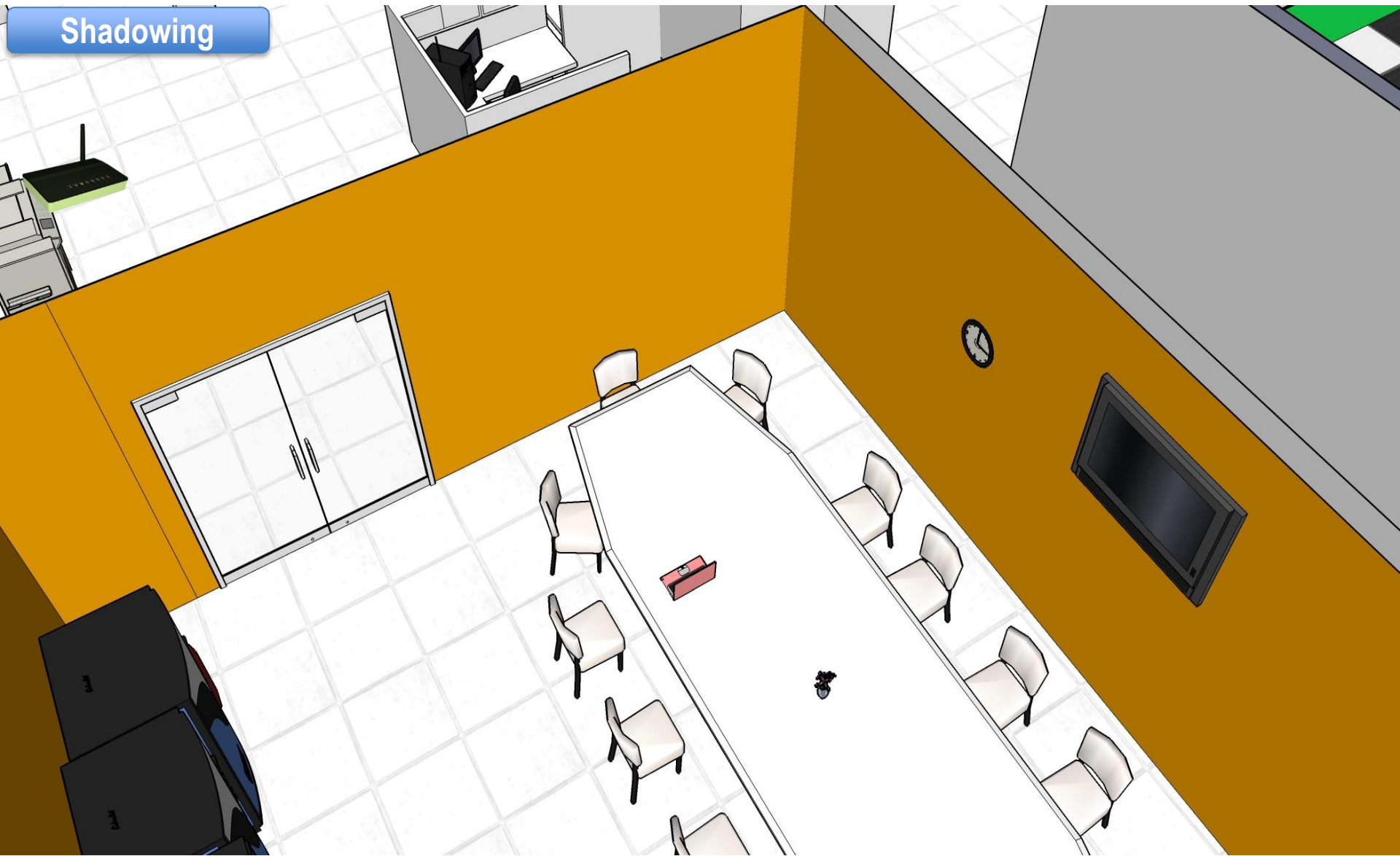
Shadowing



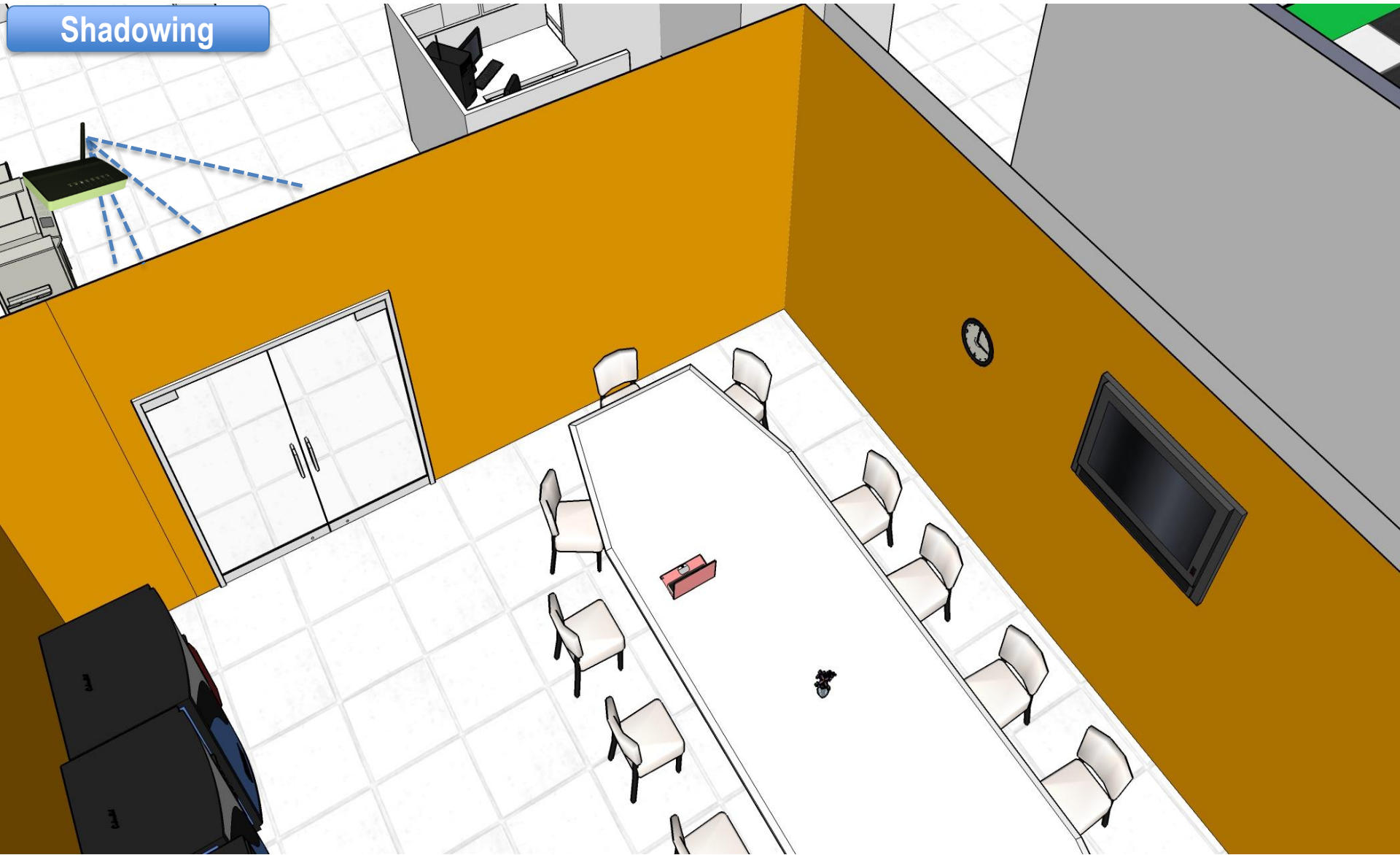
Shadowing



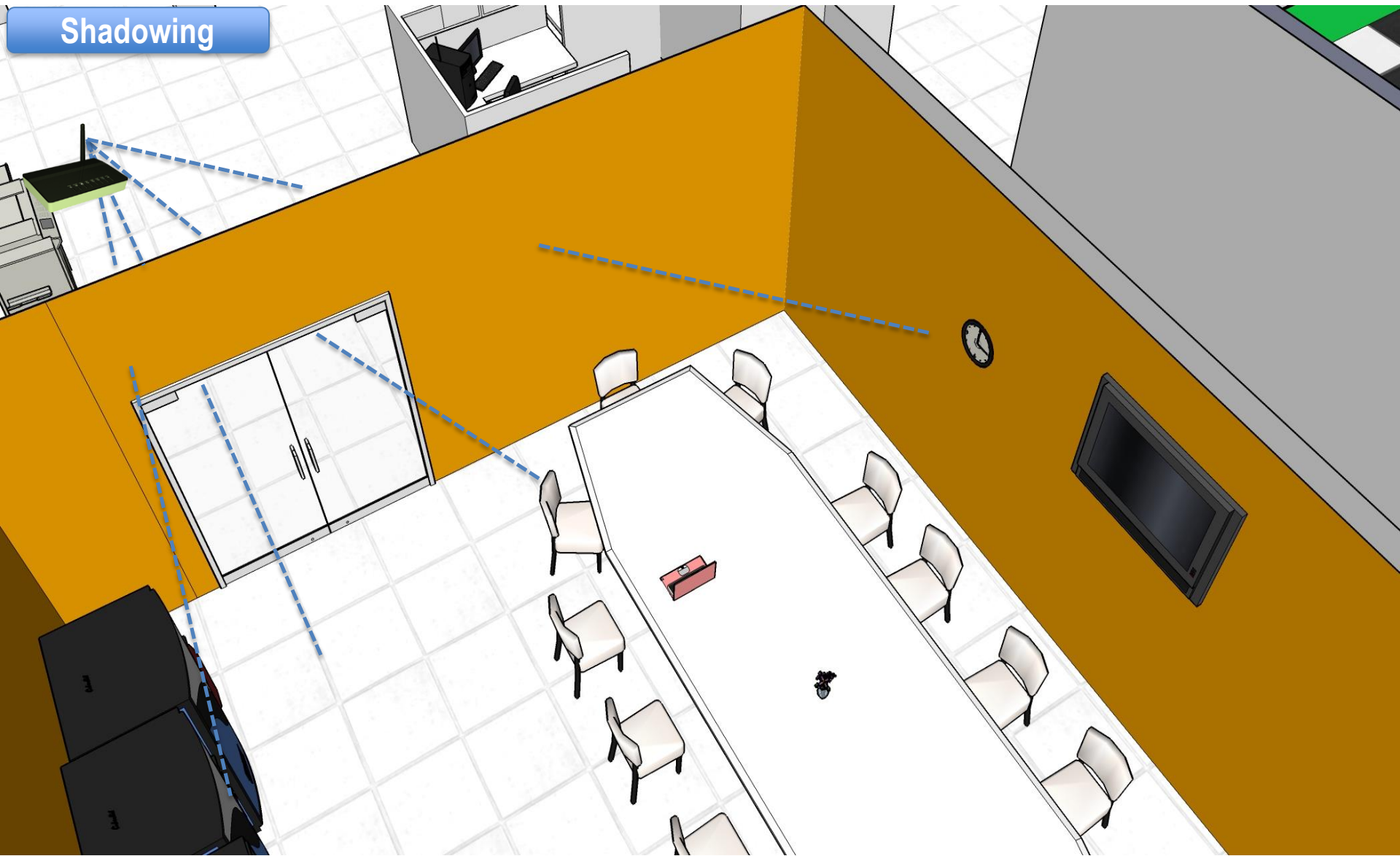
Shadowing



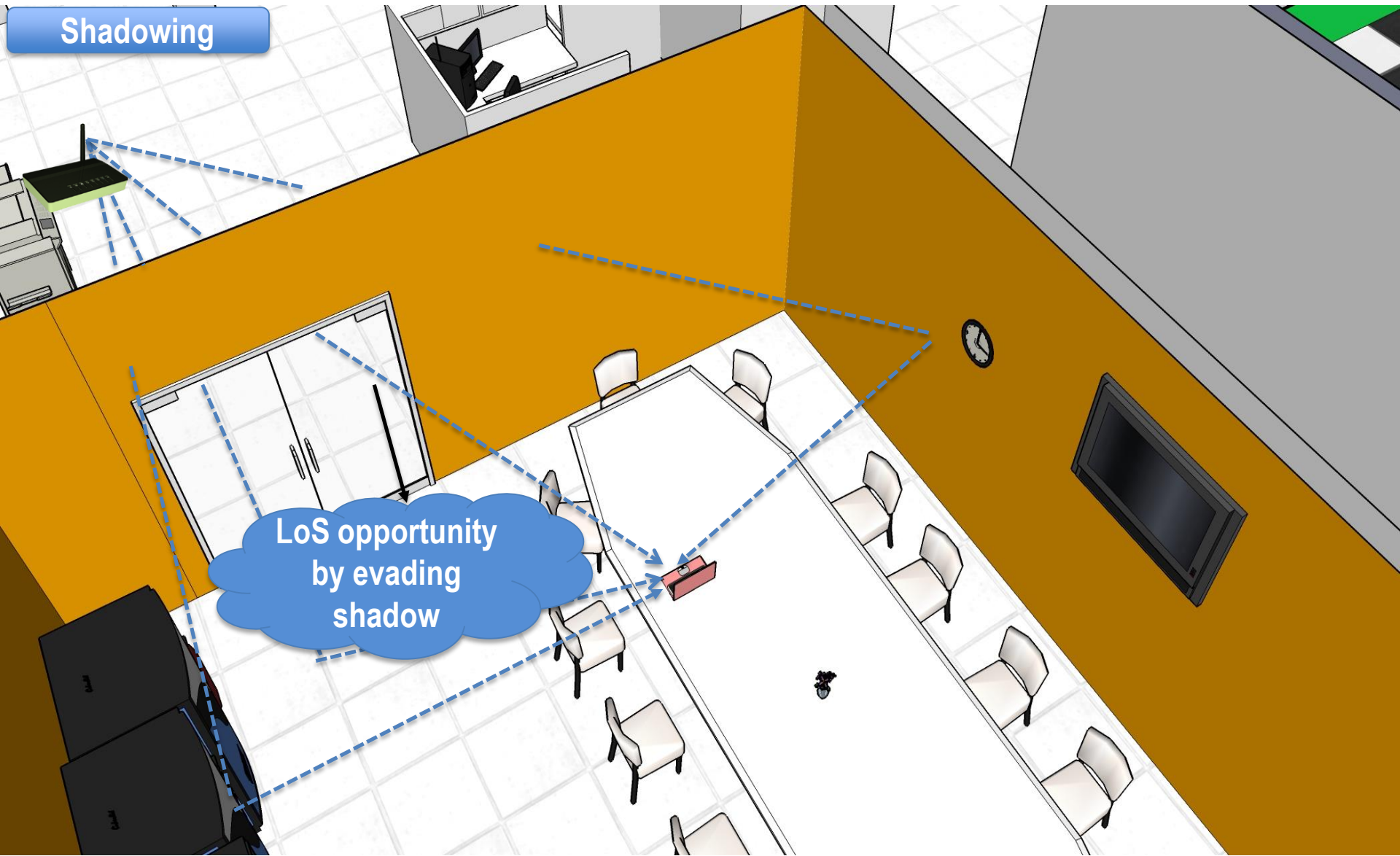
Shadowing



Shadowing



Shadowing



LoS opportunity
by evading
shadow

Regimes of Infrastructure Mobility



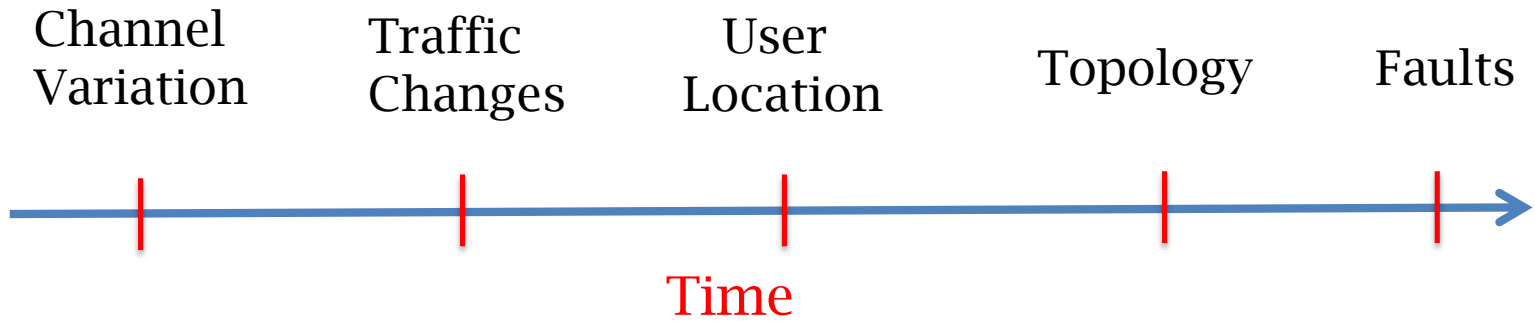
Tethered
Mobility (feet)

Ceiling Track
Mobility (meter)

Cell Tower
Relays (km)

Mobility Range

Timescales



1. What's the Killer App?

Opportunities are many:

- Better capacity
- Localization
- Improved energy
- Security
- Fault management
- QoS, reliability, prioritization,
- Software defined mobility ... scalable

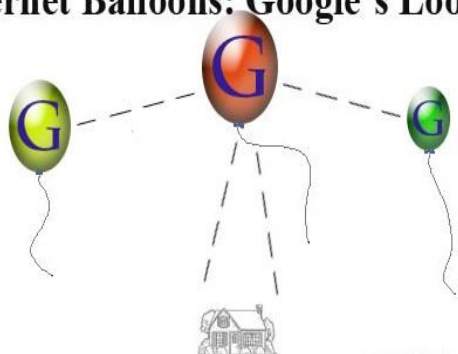
Not entirely sure about killer app

- Treating this as a bottom-up research

2. Is this Really Practical?

Robots permeating life ... design, cost, reliability, safety not major issues

Internet Balloons: Google's Loon Project



Package Delivery



Robotic Camera



Robotic Vacuum



Virtual Presence



Robotic Feet

2. Is this Really Practical?



2. Is this Really Practical?



2. Is this Really Practical?



2. Is this Really Practical?



Smart homes!

2. Is this Really Practical?



2. Is this Really Practical?



2. Is this Really Practical?



3. How Compelling are the Gains?

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Single-AP Mobility

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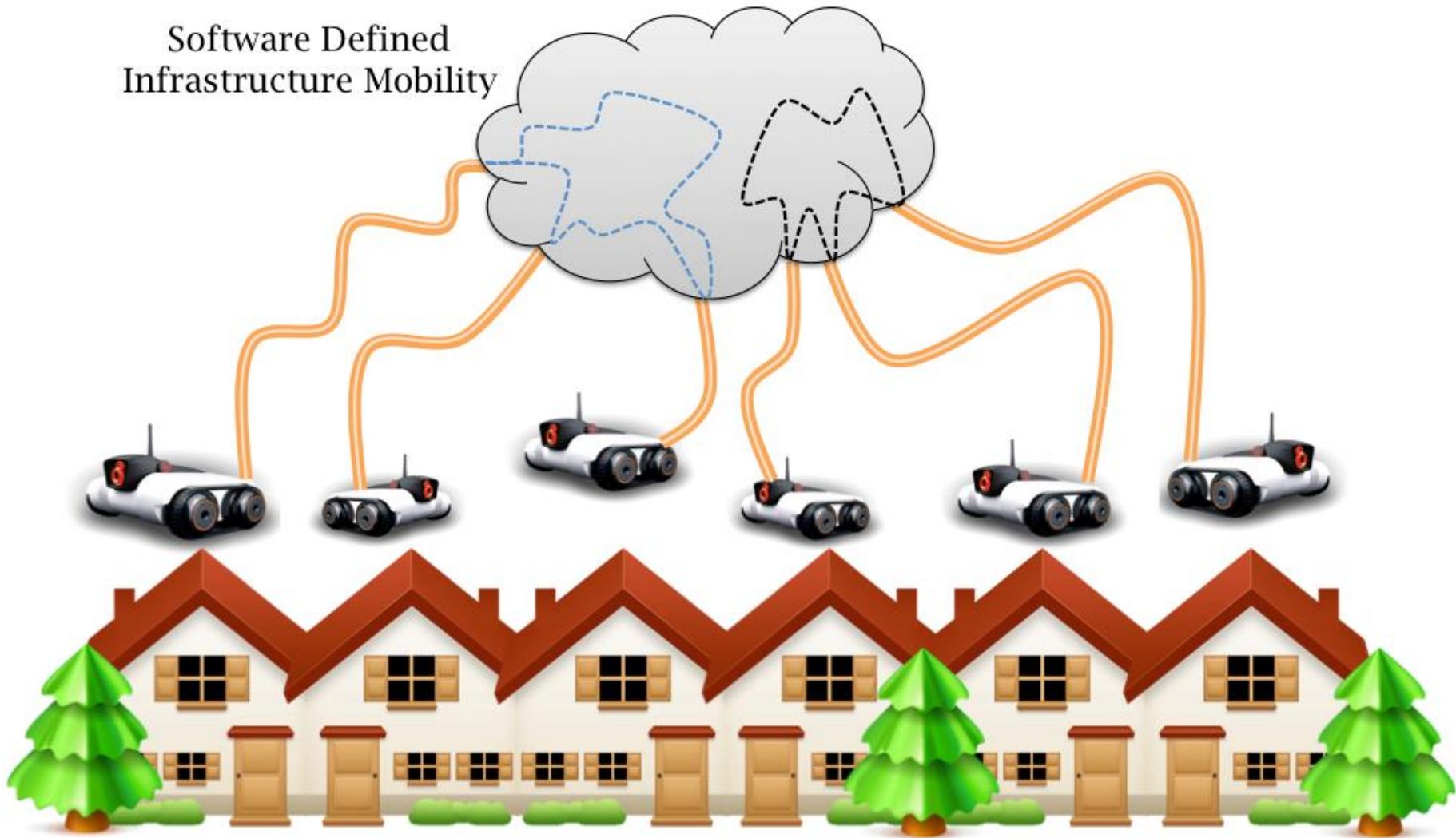
Single-AP Mobility

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 - Constructive multipath - To increase signal strength of clients
 - Destructive multipath - To decrease interference from interferers
- Upper bounds on throughput gain $\sim 2x$
- Long Range Macro-mobility can offer upto $3x$ gains

3. How Compelling are the Gains?

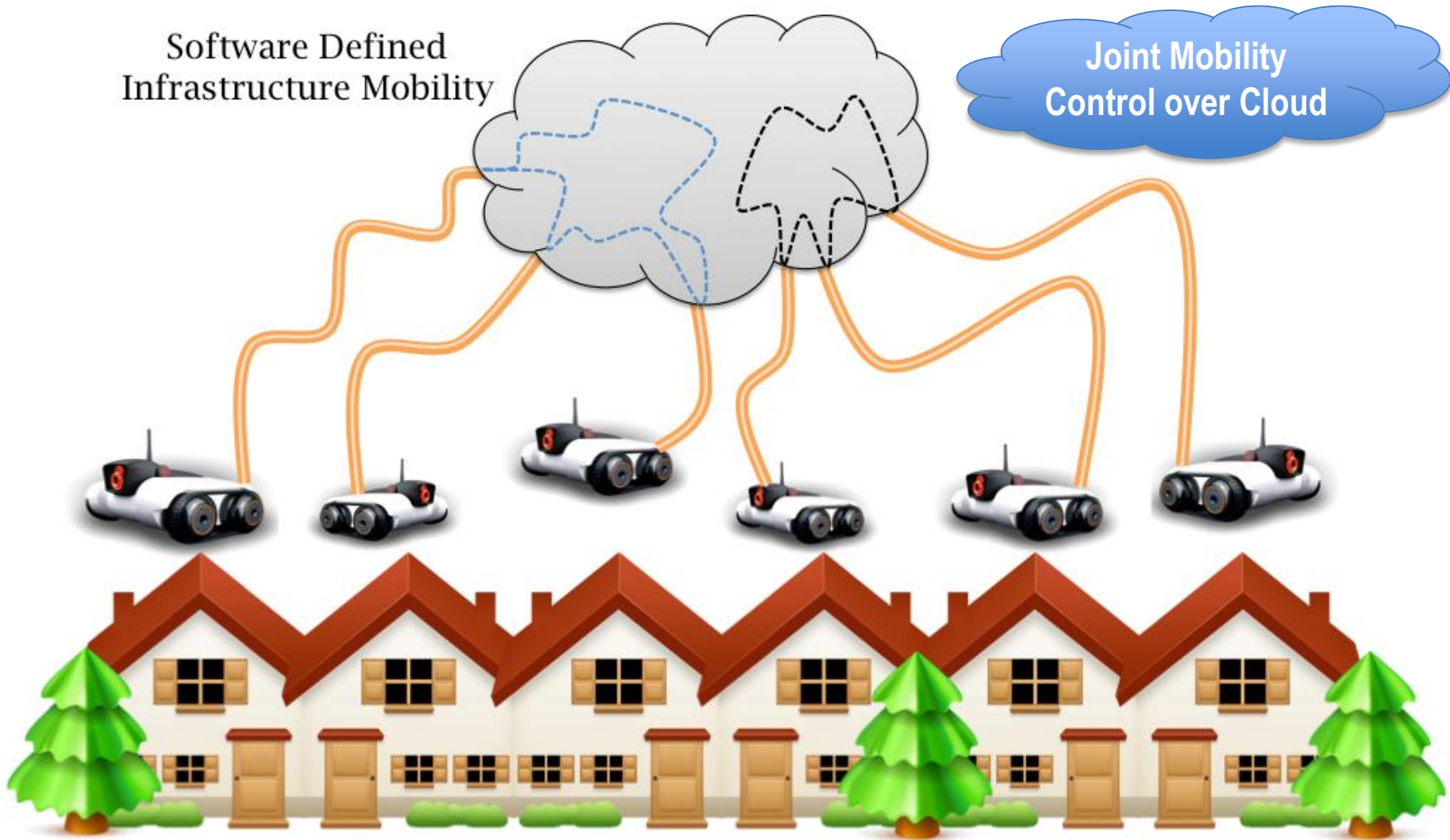
Multiple-AP Coordinated Mobility

Software Defined
Infrastructure Mobility



3. How Compelling are the Gains?

Multiple-AP Coordinated Mobility



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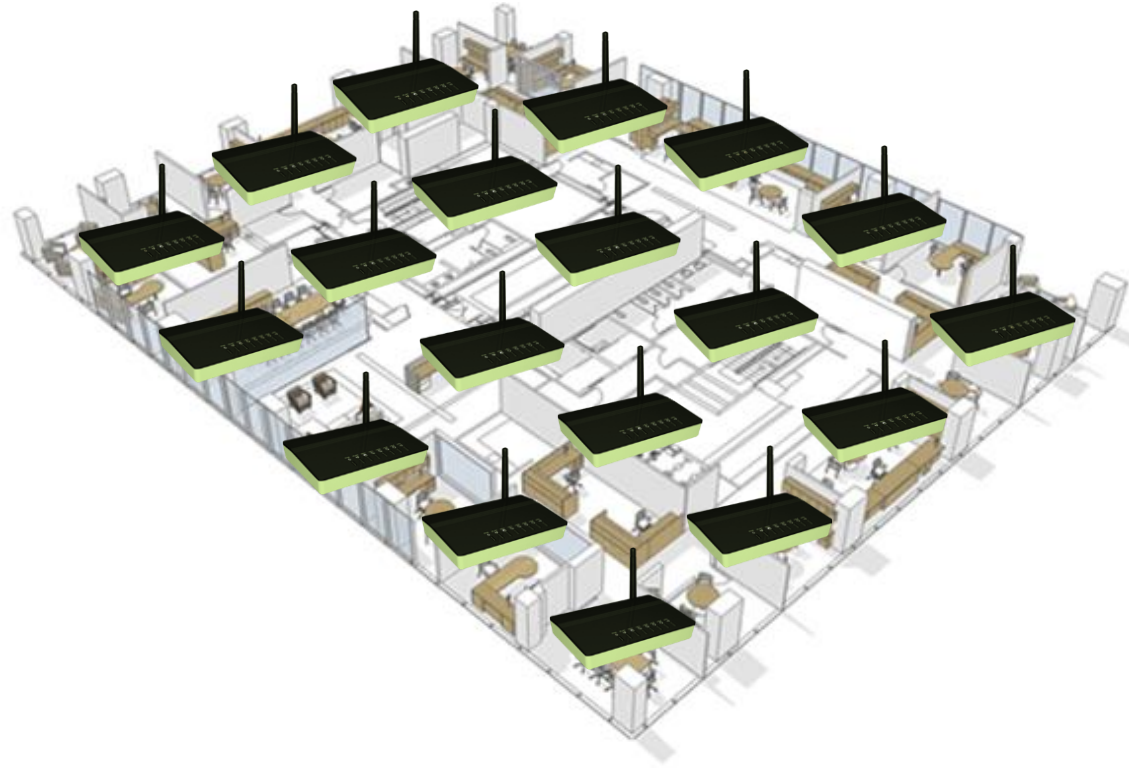
Multiple-AP Coordinated Mobility

Software Defined
Infrastructure Mobility

Upto 1.8x gains (based
on measurement driven
simulations)



4. Why not Overprovision?



Yes, that's possible.

However,

- re-wiring + Ethernet costly
- new protocols, eco-system
- backward compatibility

Robotic WiFi APs can be plug and play → backward compatible

Moreover, multiple APs can together be mobile → additional gains

Measurements

Platform: USRPs and off-the-shelf laptops

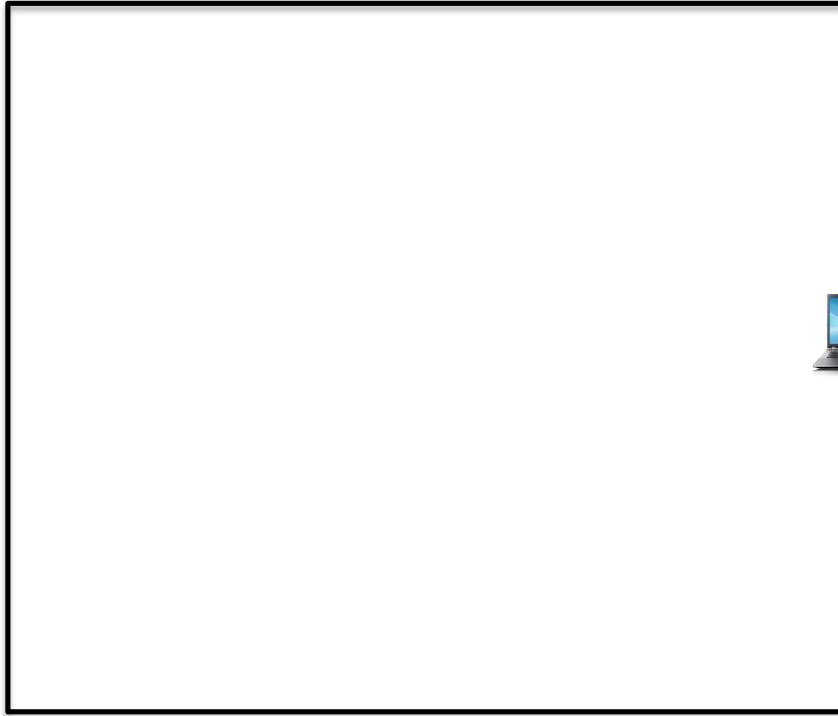


Methodology



Client

AP Mobility Area



Client



Client



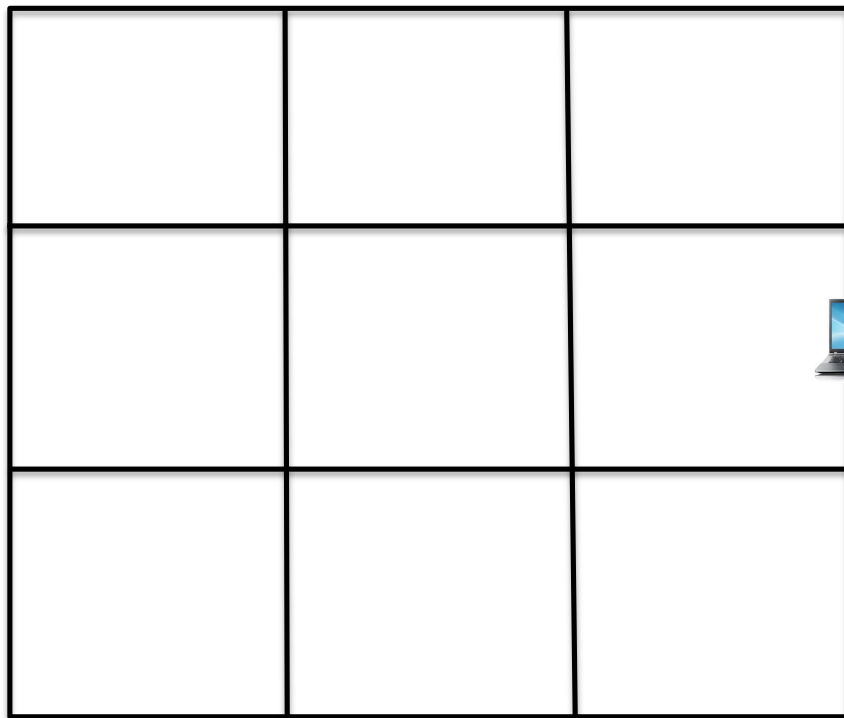
Client

Methodology



Client

AP Mobility Area



Client



Client



Client

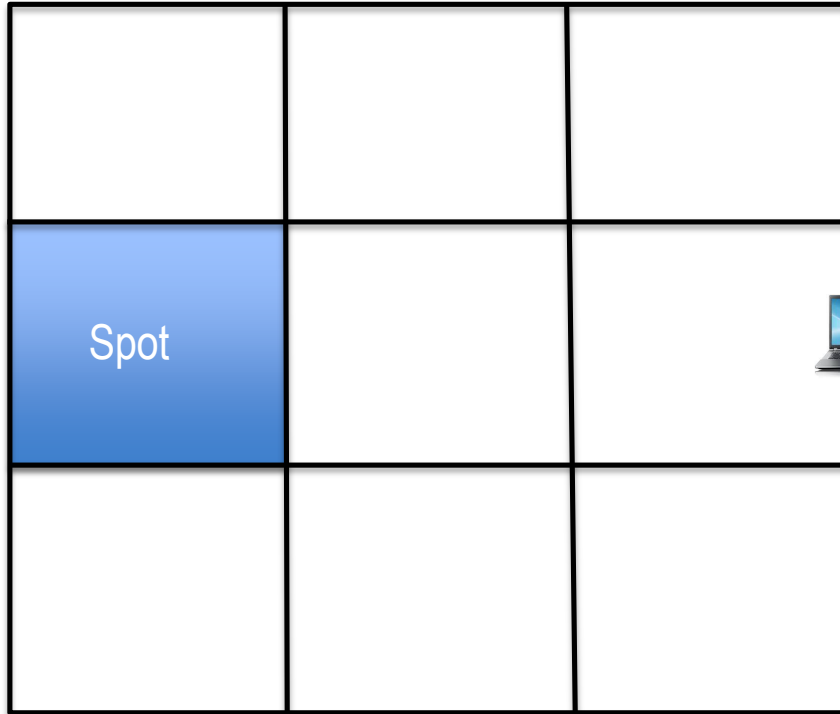
Methodology



Client

AP Mobility Area

1 foot



Client

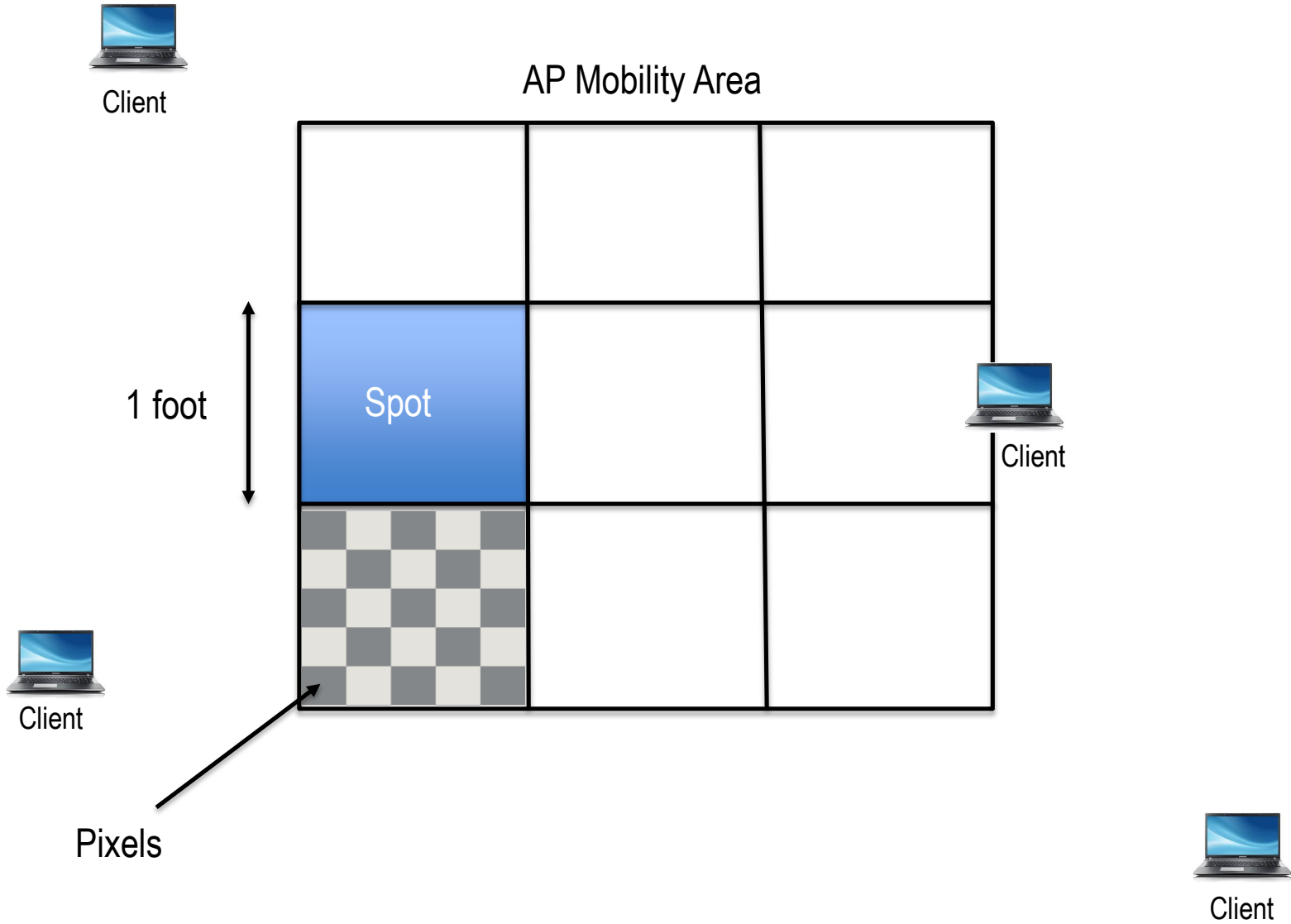


Client

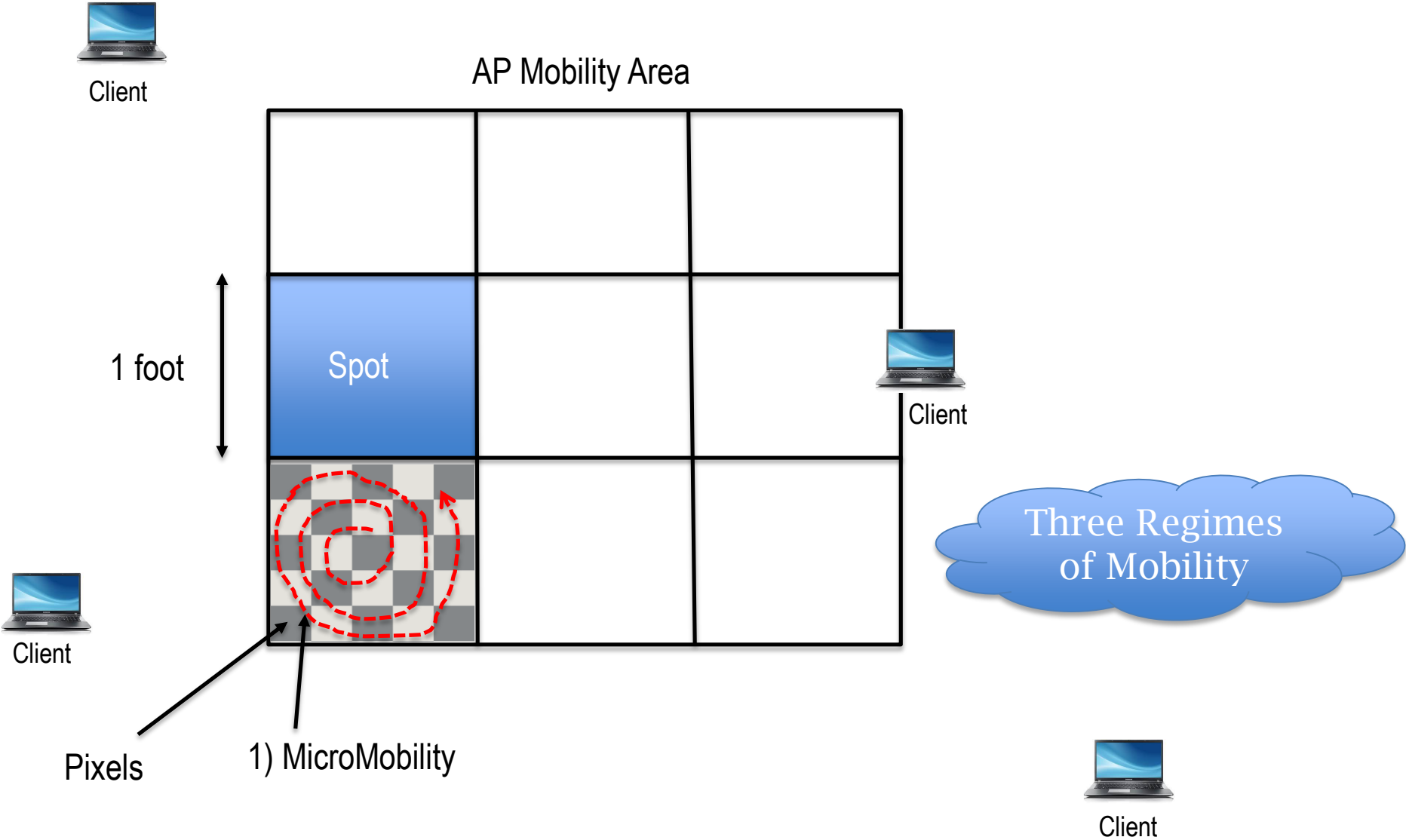


Client

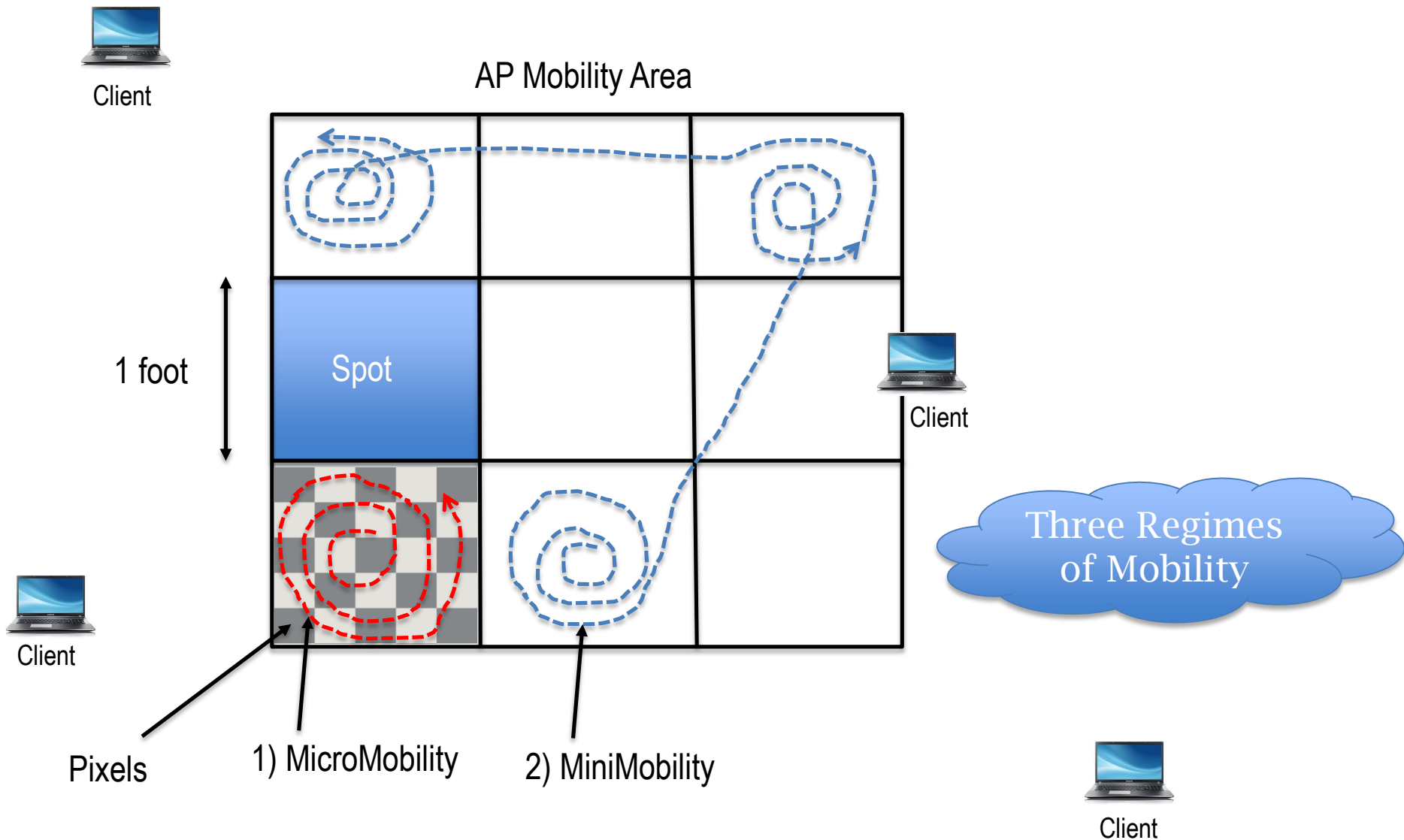
Methodology



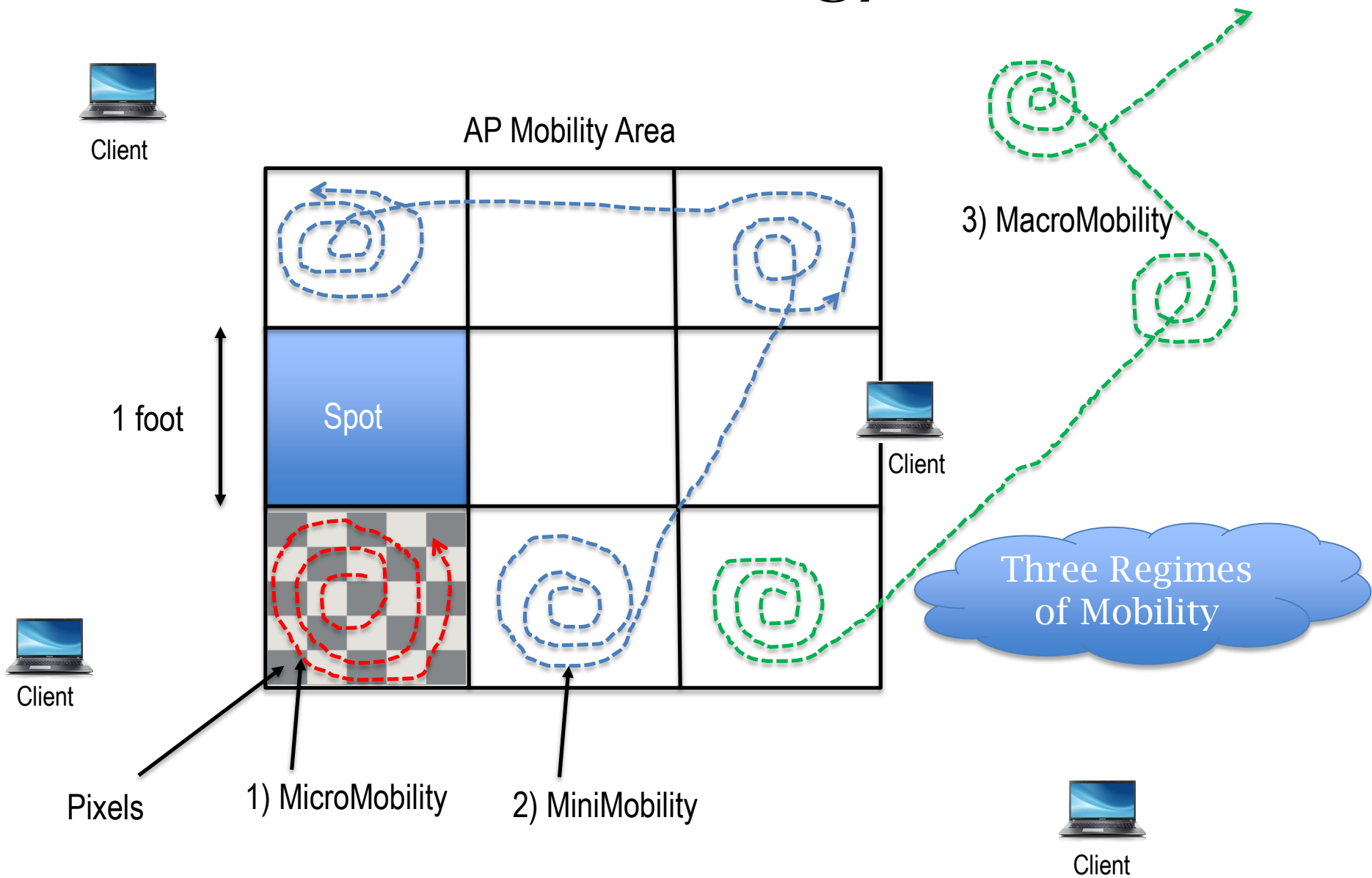
Methodology



Methodology



Methodology



MicroMobility



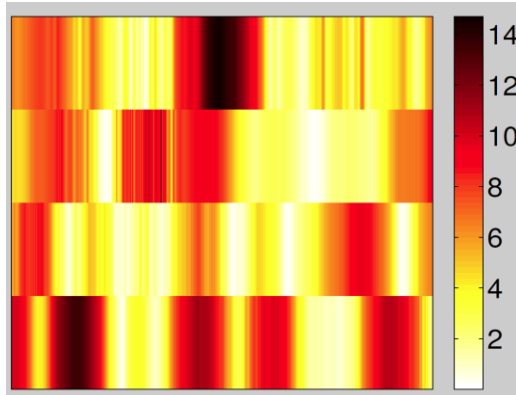
Client

MicroMobility



Client

Your AP

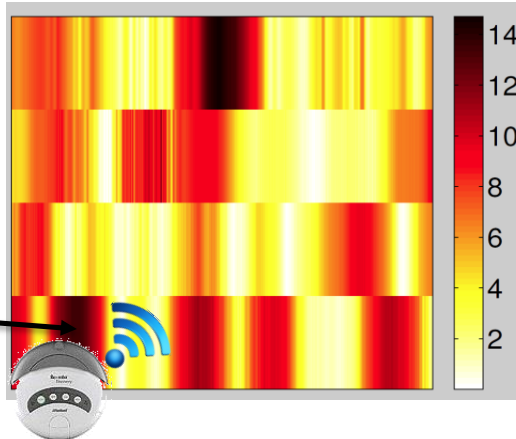


MicroMobility



Client

Your AP

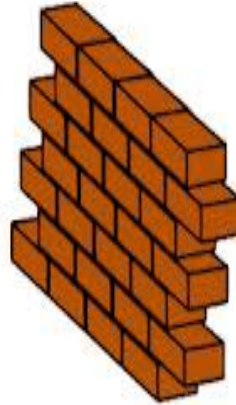


Good SNR

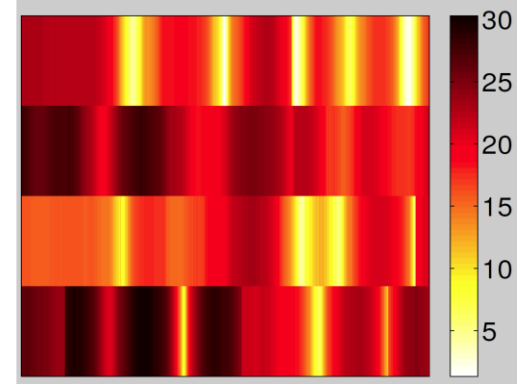
MicroMobility



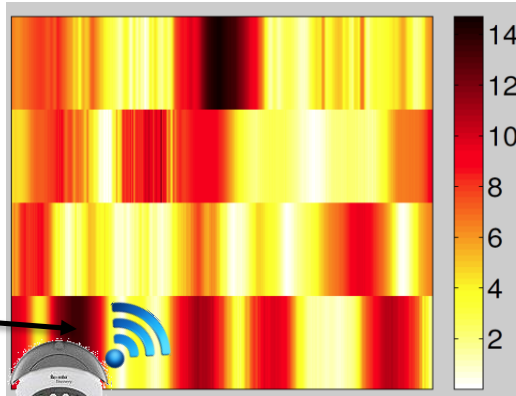
Client



Interfering (Neighbor) AP



Your AP



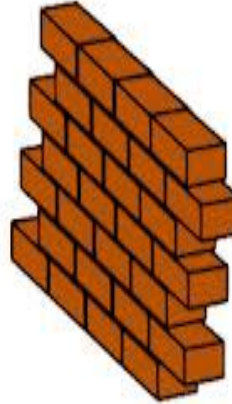
Good SNR

MicroMobility

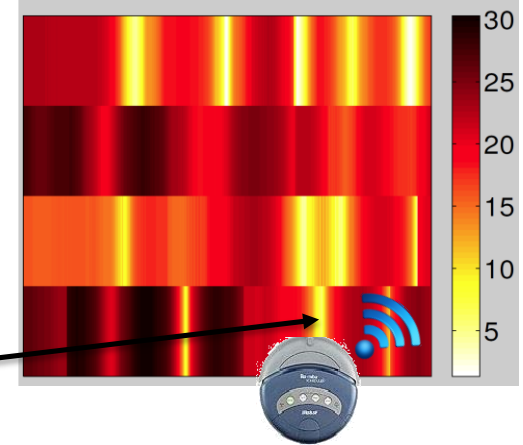
Interfering (Neighbor) AP



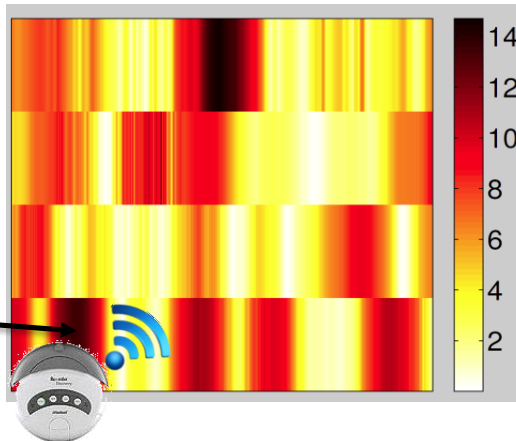
Client



Weak Interference



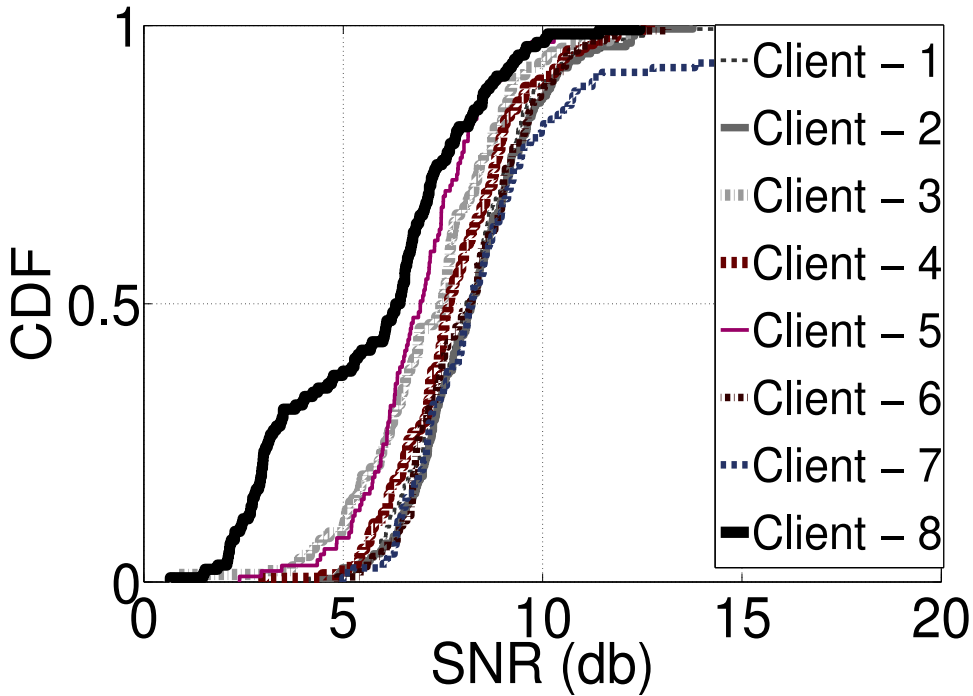
Your AP



Good SNR

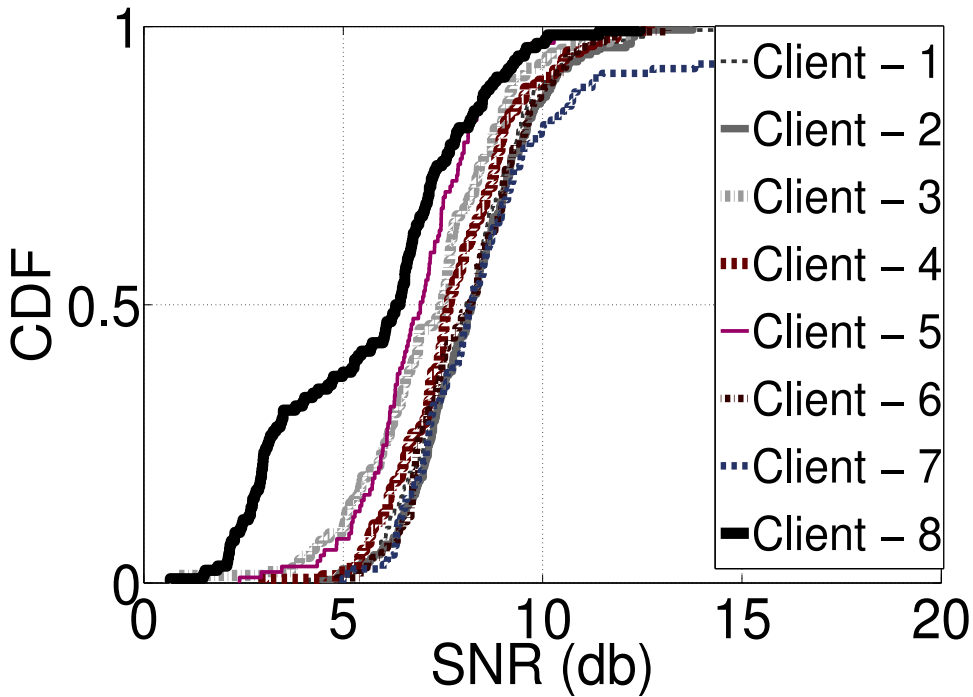
SNR Variation within a Spot

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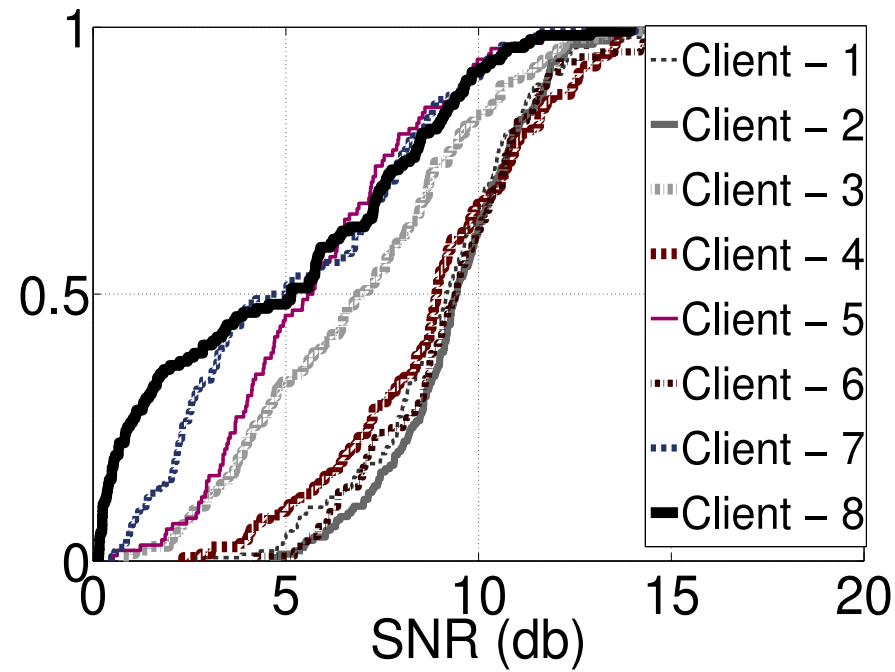


CDF of (max - median) SNR.

SNR Variation within a Spot

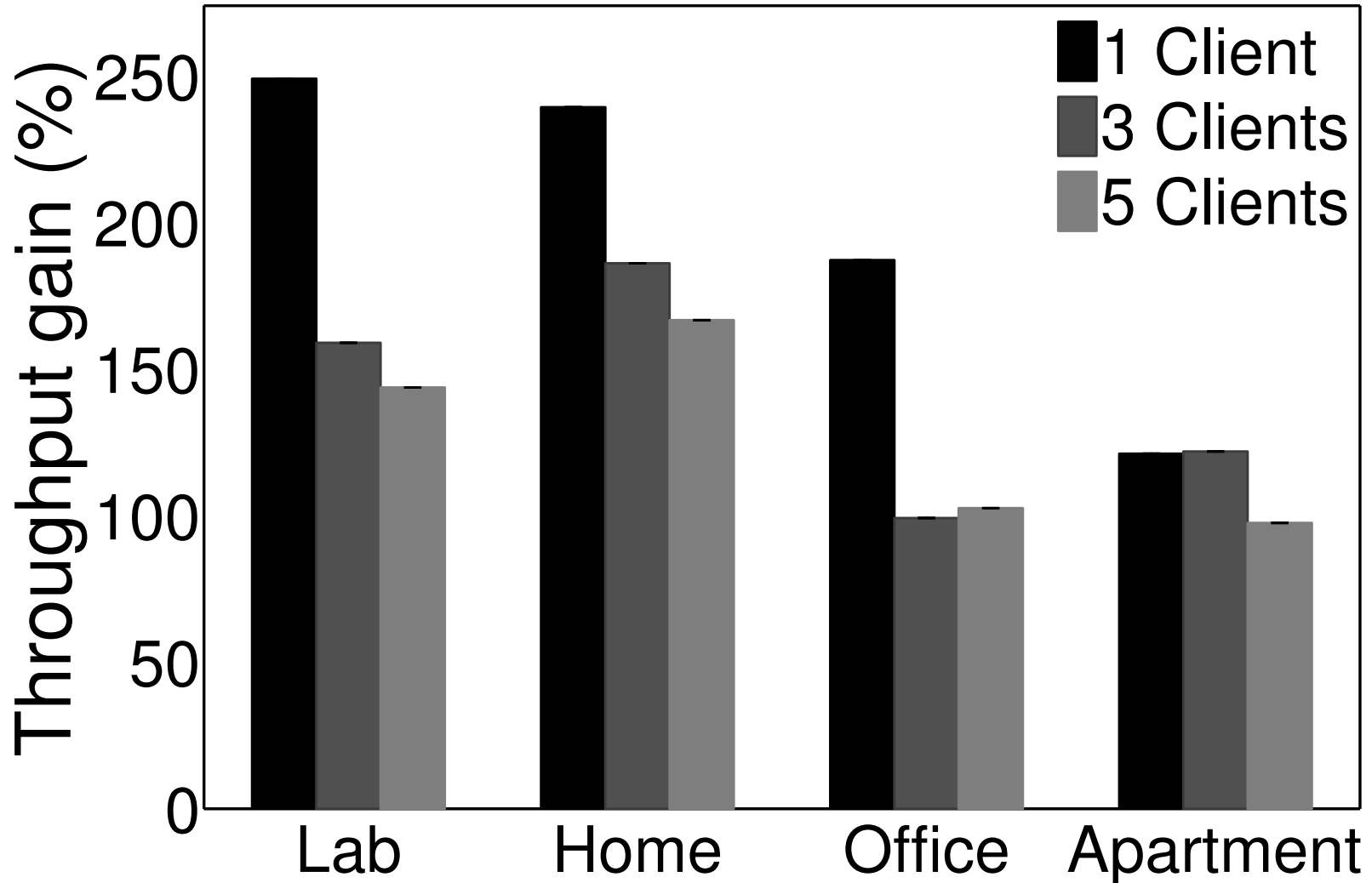


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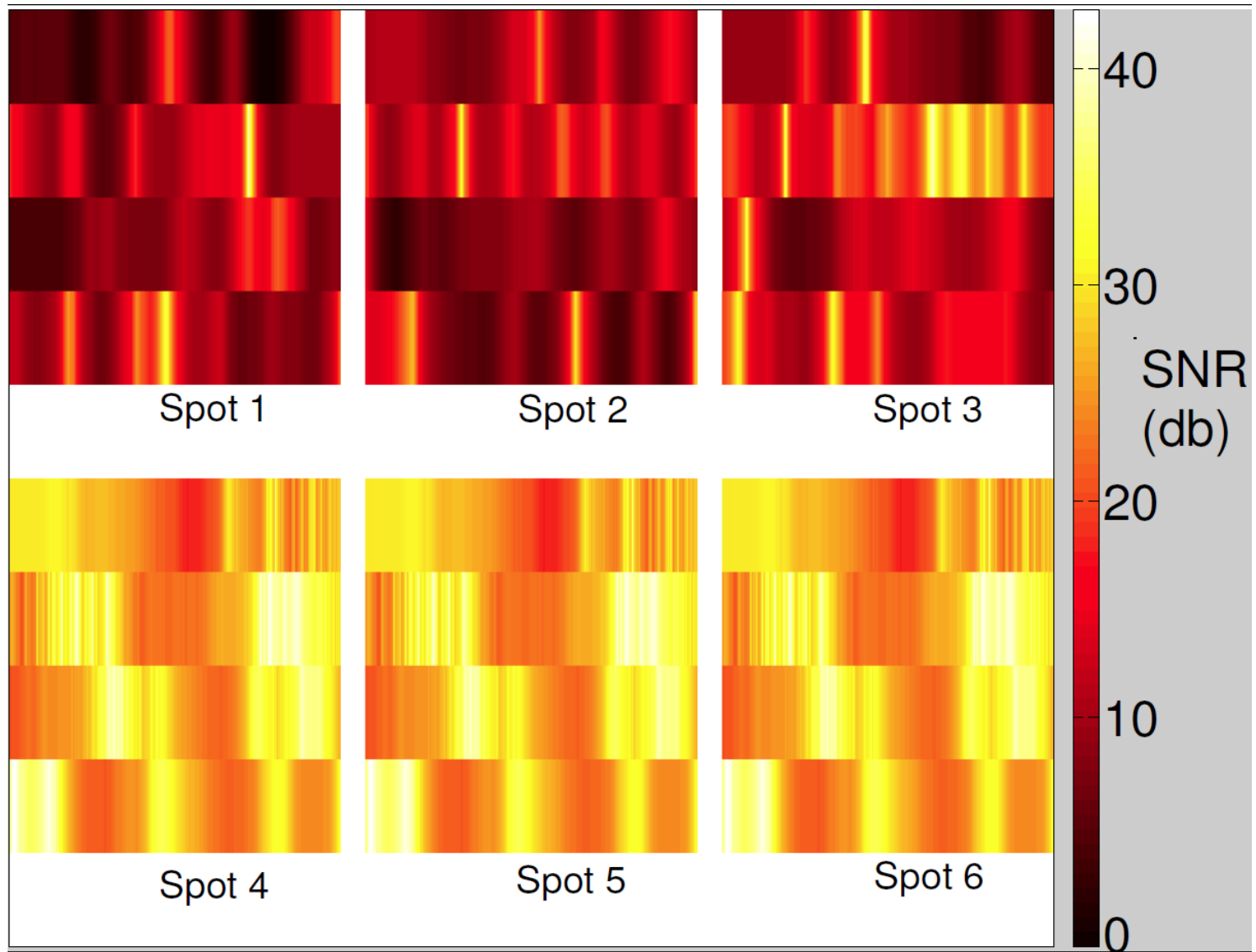


CDF of (median - min) SNR.

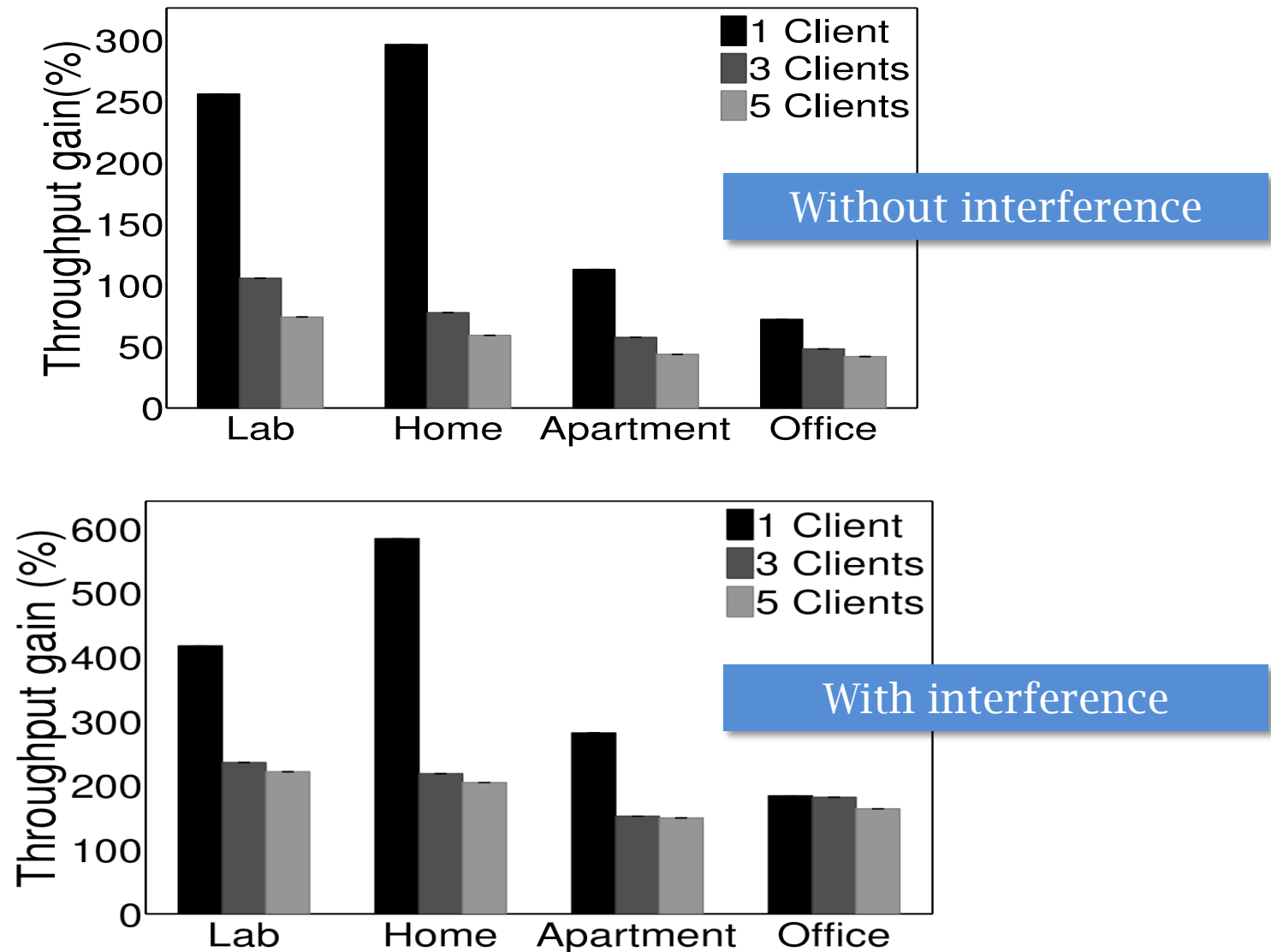
MicroMobility: Upper bound on Throughput Gain with Interference



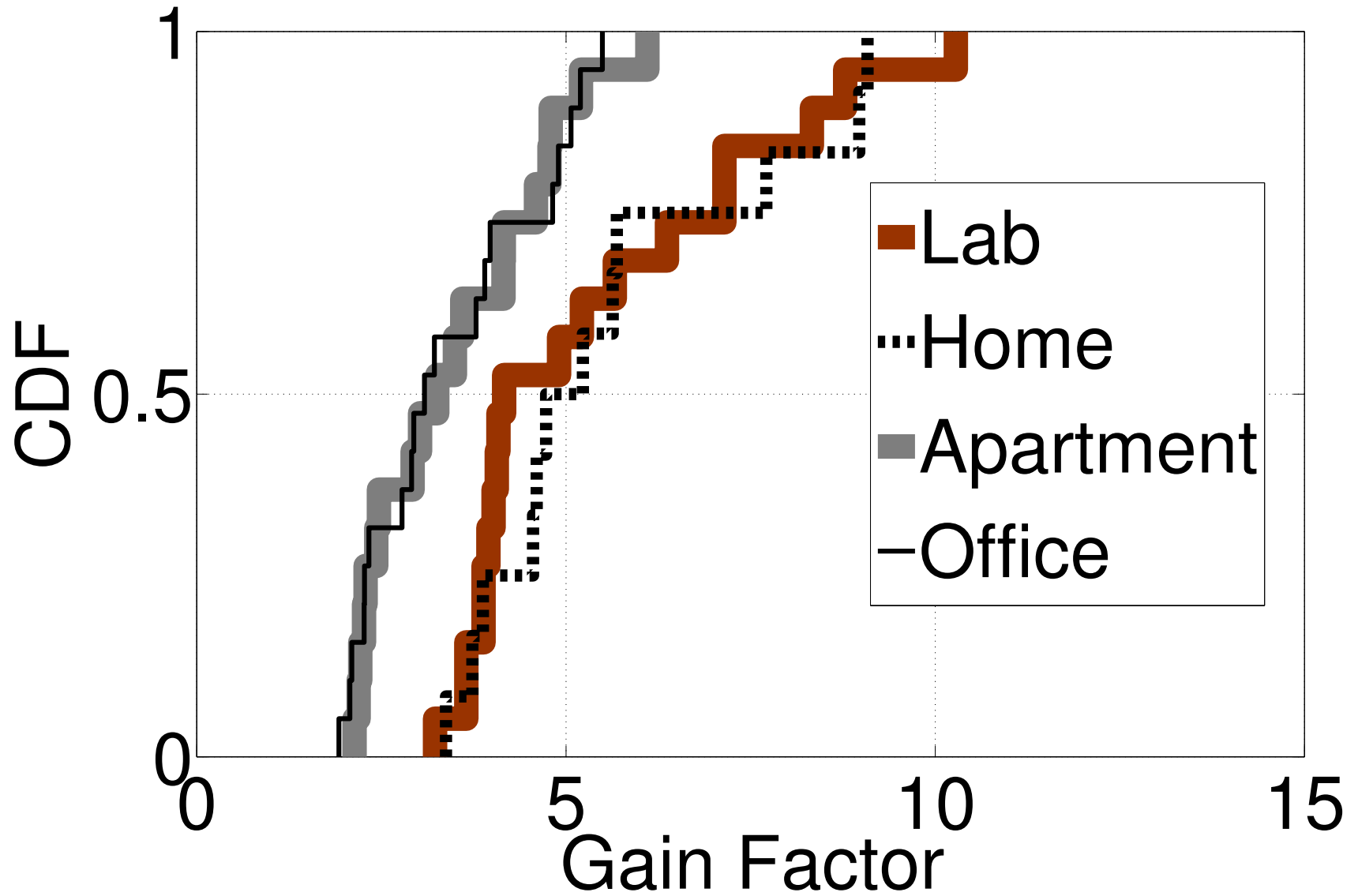
MiniMobility: SNR Variation over 6 Spots



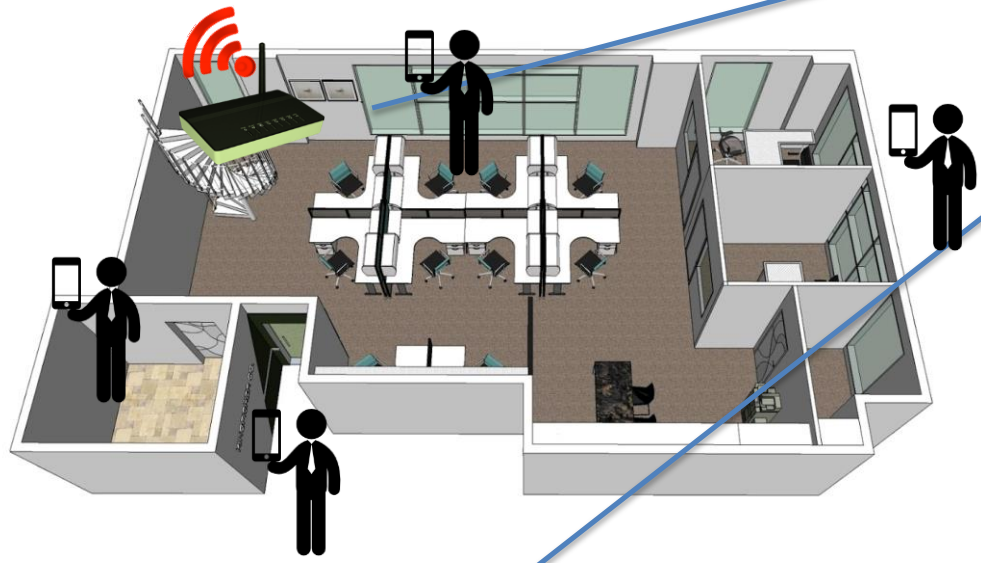
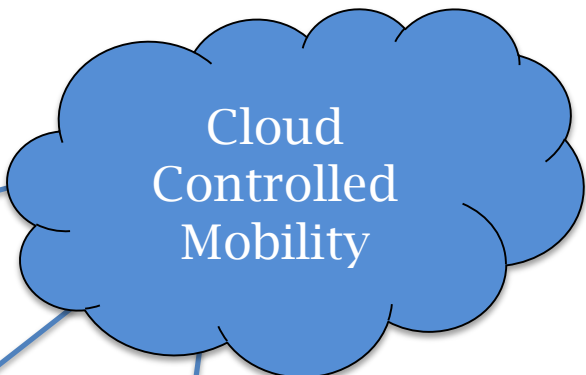
MiniMobility: Upper bound on Throughput Gain



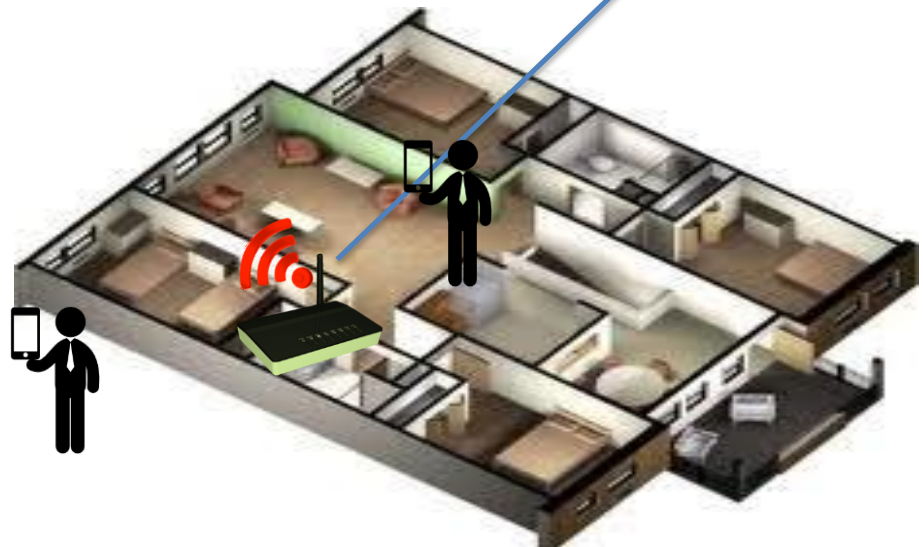
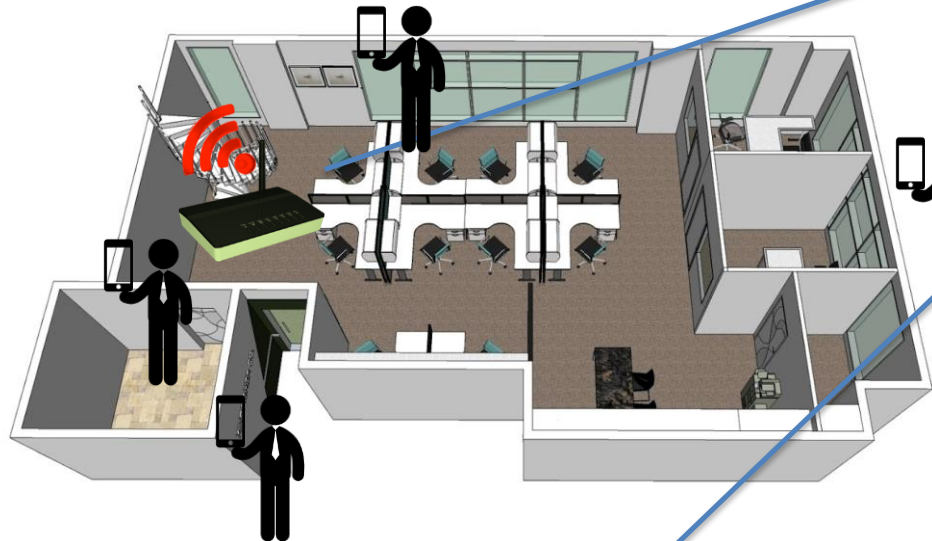
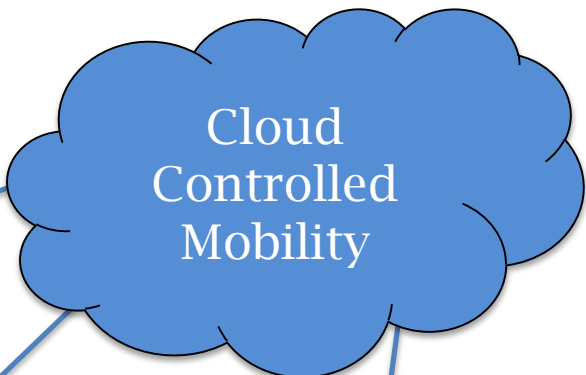
MacroMobility: Upper bound on Throughput Gain



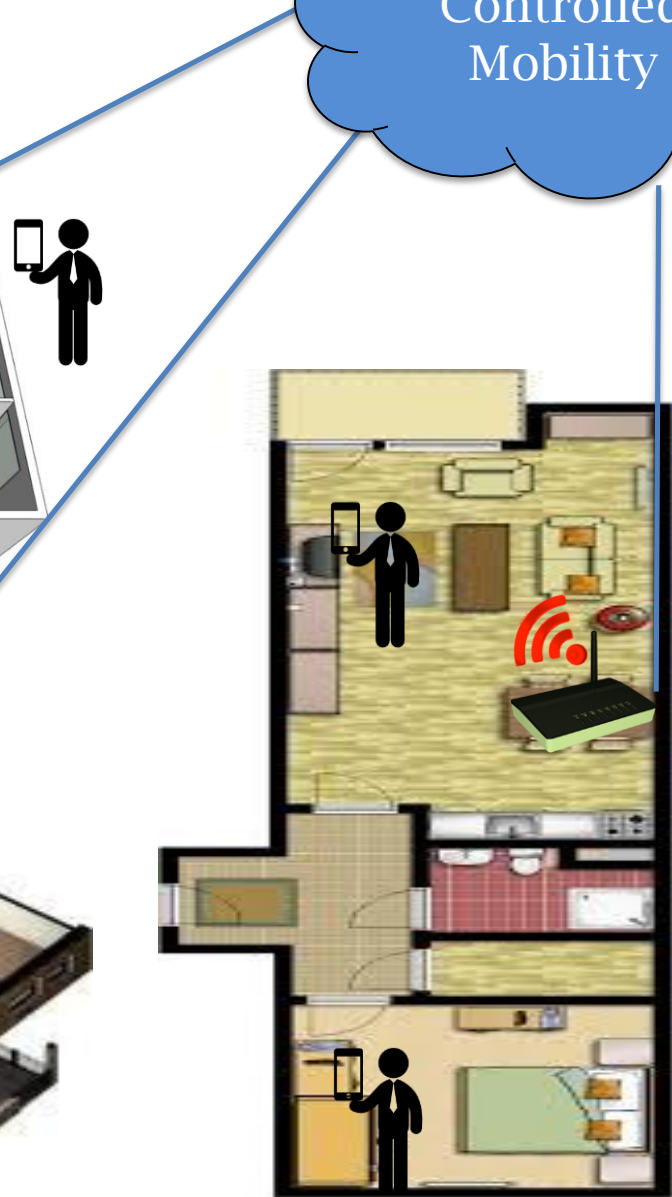
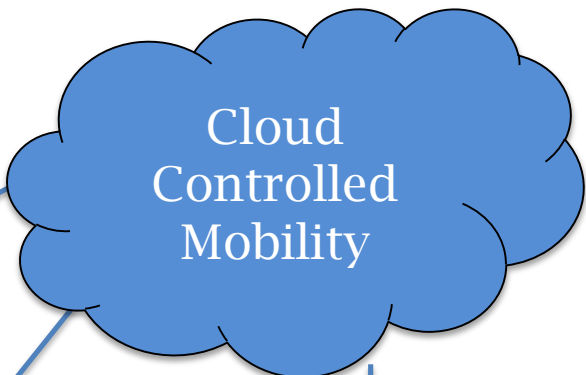
Coordinated Mobility



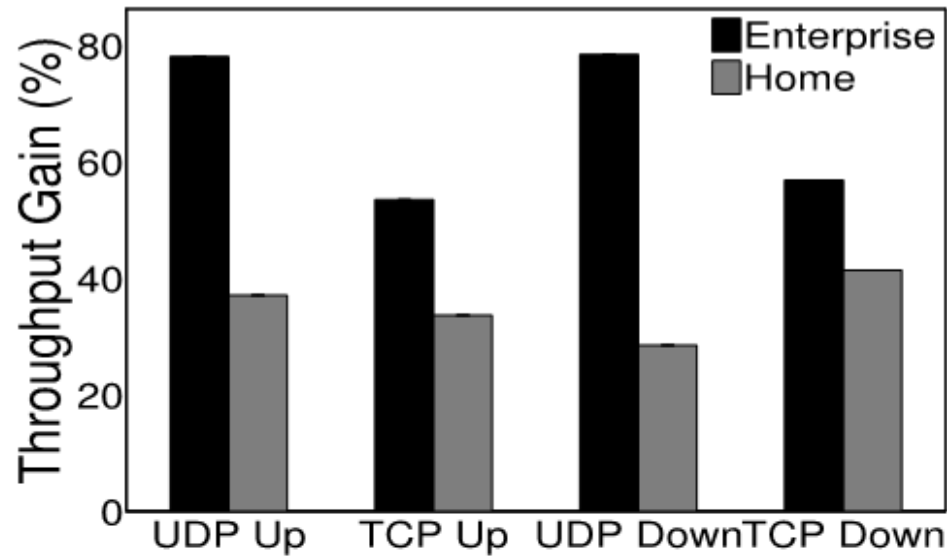
Coordinated Mobility



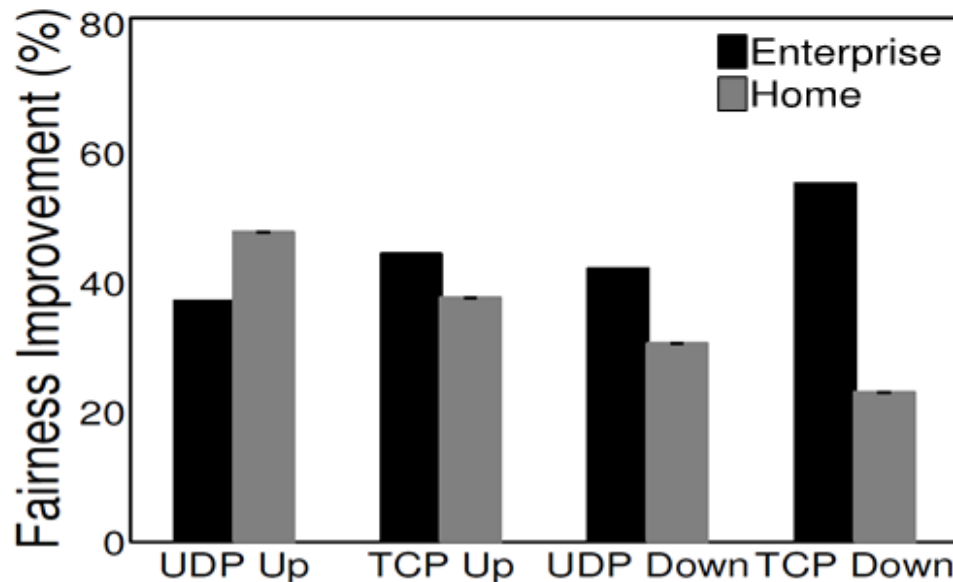
Coordinated Mobility



Coordinated Mobility Gains



30 Node, 6 AP
testbed with
measurement
based simulation



Need not Move too much

Need not Move too much

Client



Need not Move too much

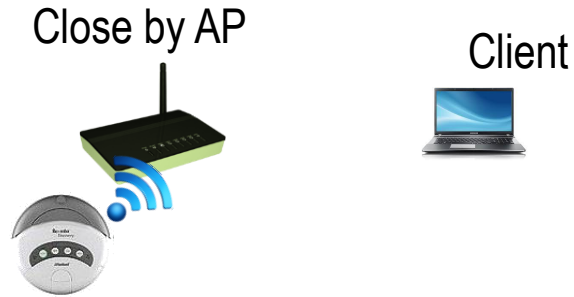
Close by AP



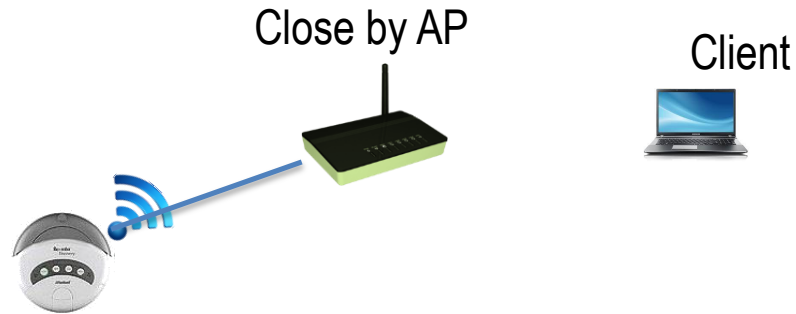
Client



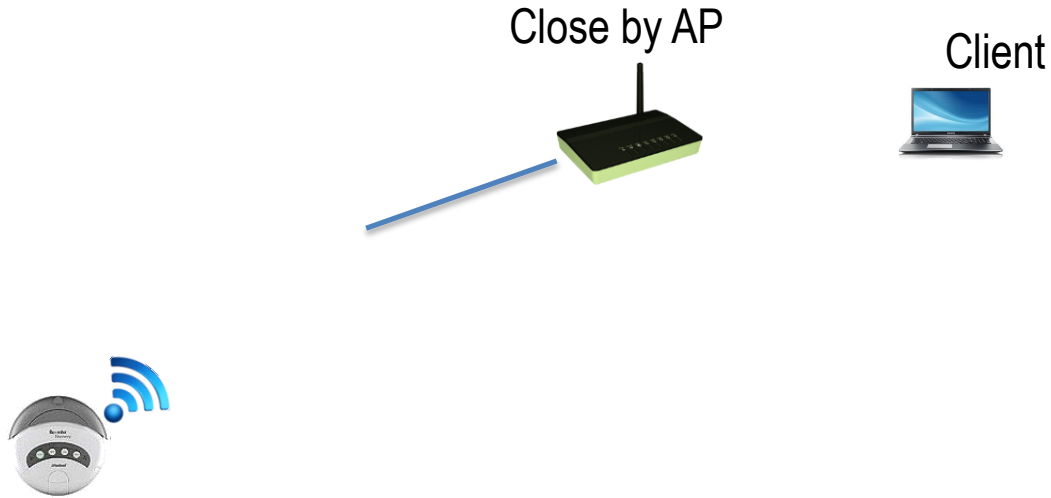
Need not Move too much



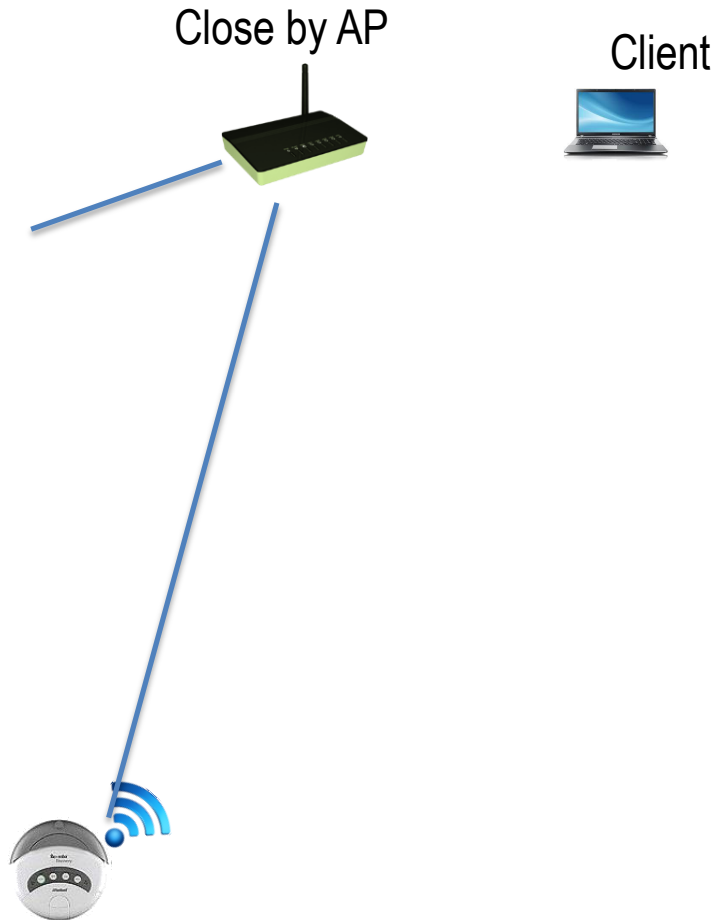
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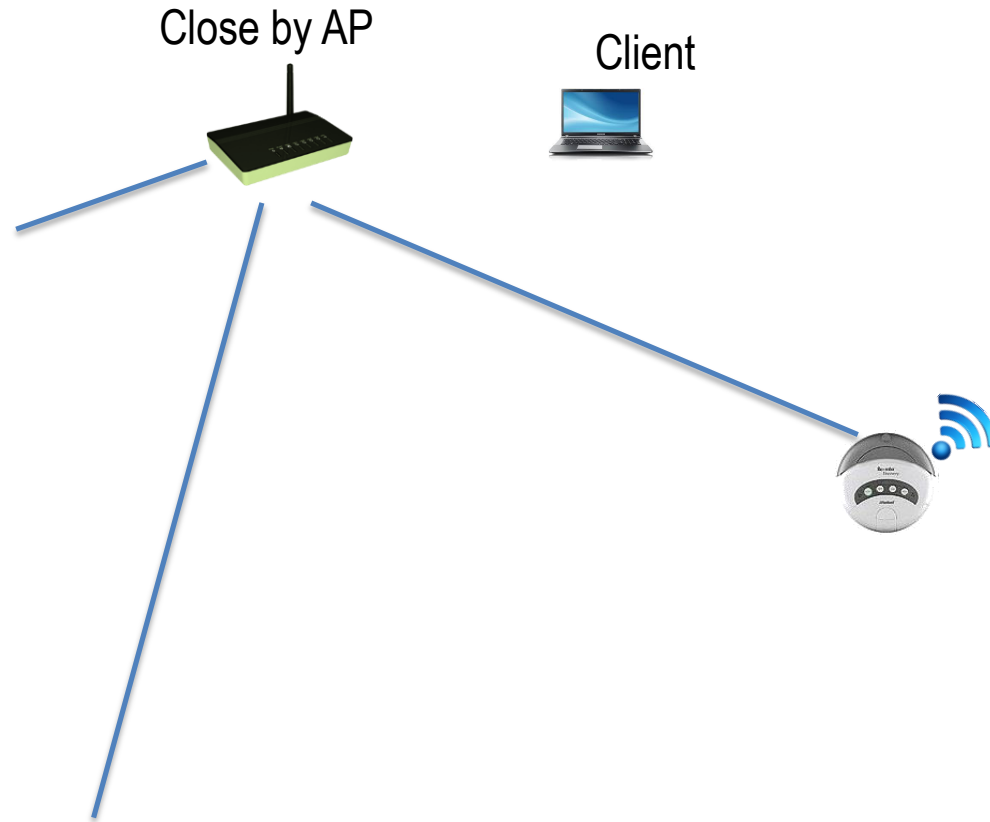
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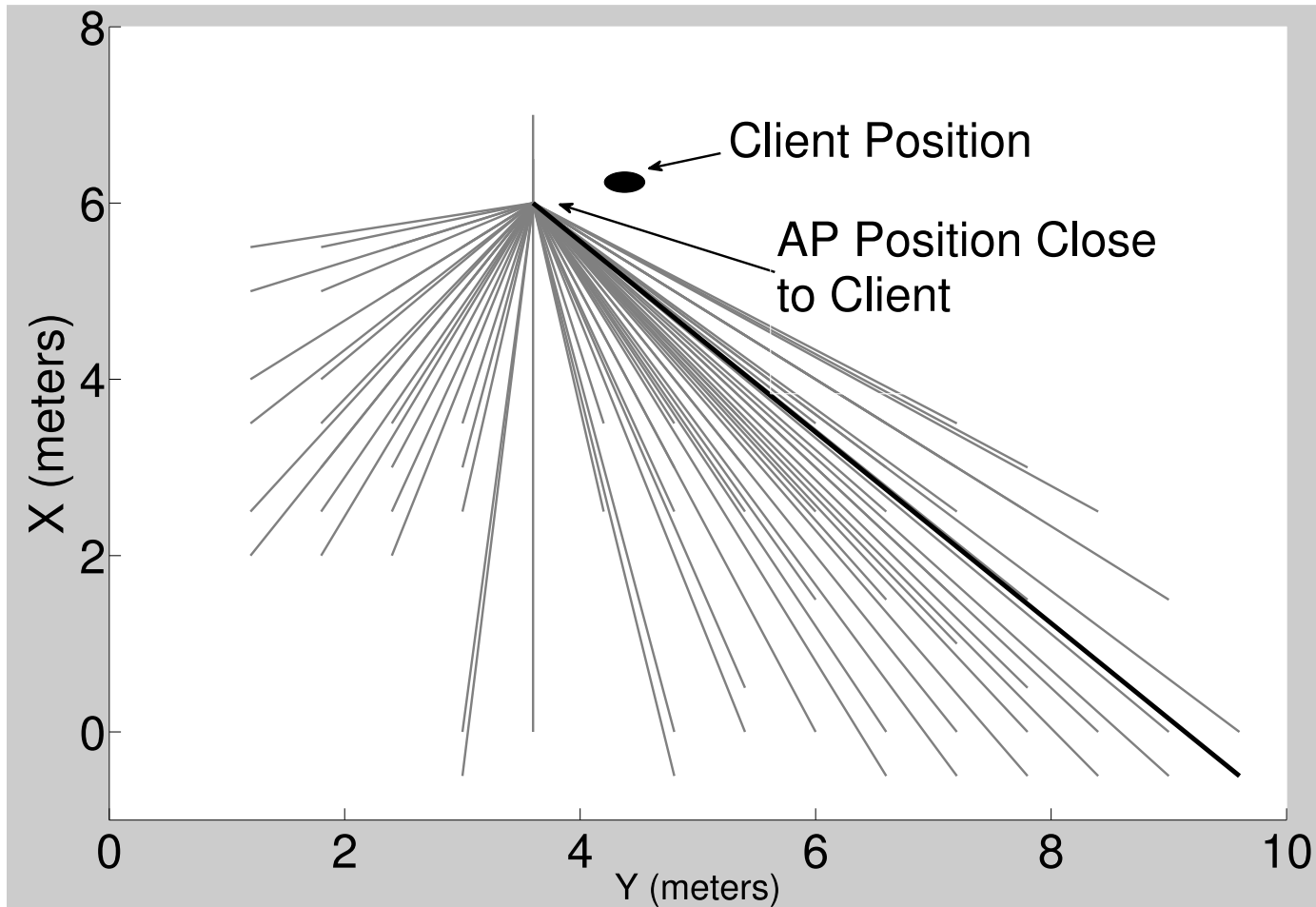
Need not Move too much



Need not Move too much



Need not Move too much



Pixels of comparable SNRs connected with a line.
Far away pixels, chosen carefully, offer strong SNRs

Many More Opportunities

- Energy savings
 - Due to greater data rates, fewer re-transmissions



- Range finding possible via careful antenna motion
 - Averages out multi-path



- More bits of secret keys from the channel
 - Through frequent antenna mobility



- Quadcopter based cell tower extension
 - Possible to avoid shadow regions
 - Channel quality at heights different from ground



Many Challenges too

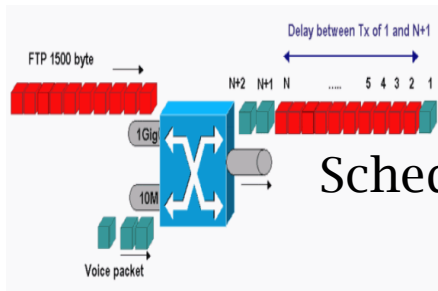
- How to relocate to the right pixel for improved SNR?
- When to relocate?
- Joint mobility and power control, channel management
- Optimizing for multiple clients. New scheduling schemes
- Mobility planning in between protocol idle periods
- Leverage overheard transmissions for mobility decisions
- Improved multi-AP coordination
- Many others ...

Take Away

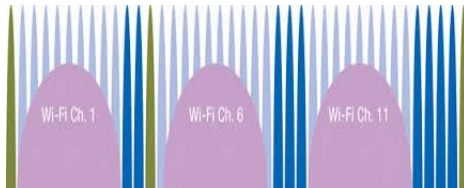
Power Control



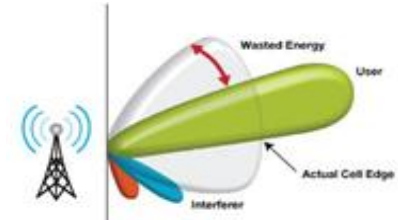
Scheduling



Channel Selection



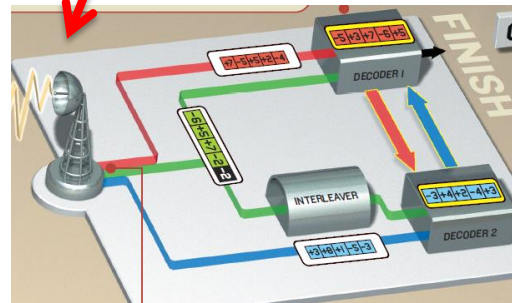
Beamforming



MIMO



Coding



Take Away



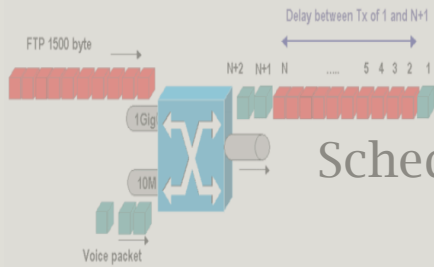
Infrastructure
Mobility



Power
Control



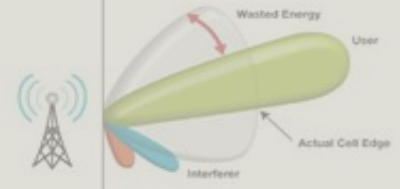
Scheduling



Channel
Selection



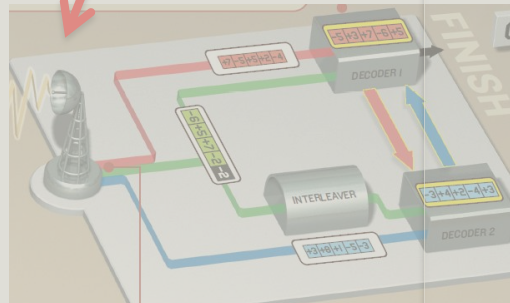
Beamforming



MIMO



Coding



Thank You!

Questions?



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