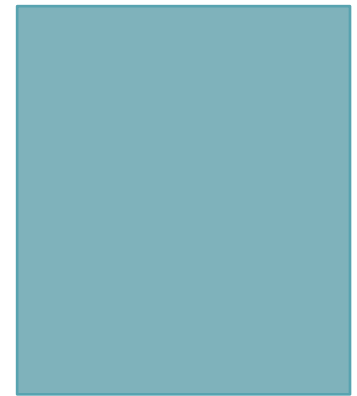




PSCR



2015 Public Safety Broadband Stakeholder Meeting

Public Safety Communications: How to Maintain Connectivity and Improve Resiliency?

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This work is sponsored by:



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Outline

- ▣ Motivation
- ▣ Evaluation methodology
 - ▣ Scenarios
 - ▣ Performance metrics
- ▣ Effects of outages on network performance
 - ▣ Network-level scenario
 - ▣ Site-level scenario
- ▣ Resiliency strategies
 - ▣ Traffic control
 - ▣ High-power UE
 - ▣ Parameter configuration
 - ▣ Device to device communication
- ▣ Summary

Motivation

- ▣ Network deployments are subject to:
 - ▣ Planned “failures”
 - ▣ Maintenance
 - ▣ Site relocation
 - ▣ Unplanned failures
 - ▣ Construction errors (“backhoe fade”)
 - ▣ Incidents/natural disasters/power loss
 - ▣ Equipment failure
 - ▣ Theft/vandalism/equipment misuse
 - ▣ Administrative errors (misconfigured system parameters)

- ▣ First responders need to be “connected” anywhere, anytime

⇒ *How can users maintain connectivity when sites fail?*



High winds win over tower's ability to brace them
December 18, 2009 - Winds estimated to be in excess of 100 mph on December 8 were credited with toppling this 143-foot tall self supporting tower on top of Buck Mountain in Ruidoso, N. Mex. The structure is owned by White Mountain Communications of Roswell.

Carriers on the tower were Alltel Communications, Verizon Wireless, MTD Radio (FM Station) several two way carriers and one LP FM. Restoration work is being done by Greens Tower Services of Tulsa, Ok. Photo Courtesy: Steve Kitchens

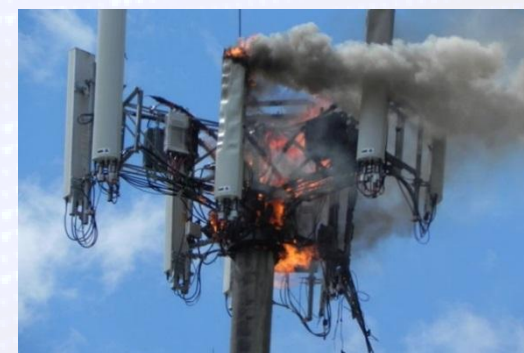


Image sources:

http://www.wirelessestimator.com/t_content.cfm?pagename=Cell_Tower_News_12.09

http://www.wirelessestimator.com/t_content.cfm?pagename=breaking_news.cfm6.30.11

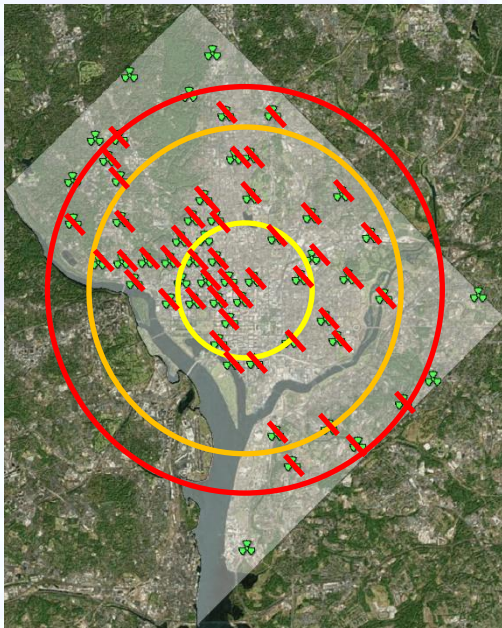
http://www.mynews13.com/content/news/cfnews13/news/article.html/content/news/articles/cfn/2013/8/21/cell_phone_tower_cat.html

Evaluation Methodology

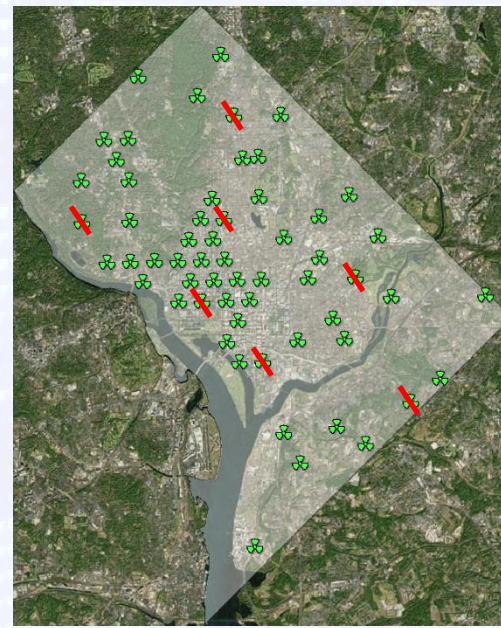
- ▣ Investigate different resiliency strategies to maintain a level of coverage and connectivity regardless of the network status
- ▣ System failures in a deployed site plan are modeled by deactivating sites and examining the effects on the network performance
 - ▣ Site deactivation models both localized and random outages
- ▣ We use RF planning (InfoVista's Mentum Planet) and network simulation tools (NS-3) to model each resiliency strategy to capture the network-level and communication protocol interactions respectively
- ▣ Performance metrics include:
 - ▣ Statistical averages to evaluate coverage and capacity
 - ▣ Transient effects to capture dynamic range and connectivity

Network-level Scenario

- Given a percentage (random or localized) outage for a site plan, what is the resulting public safety user coverage?
- How to maintain coverage during outages?



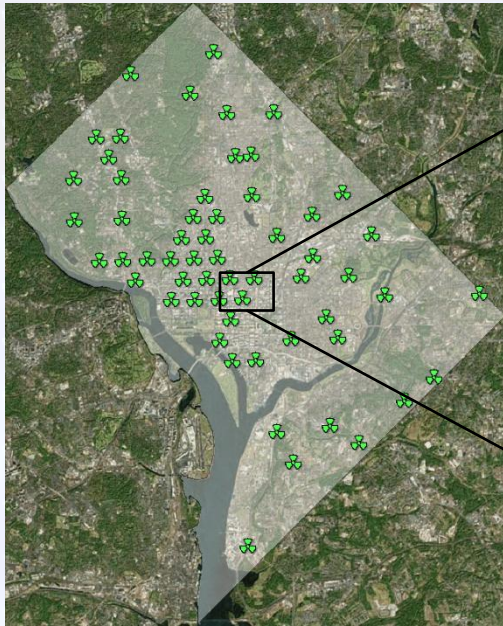
Localized Outages



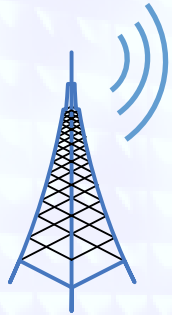
Random Outages

Site-level Scenario

- A group of first responders are called to an incident in an area where sites may be down
- Responders communicate with each others (via application-level broadcast)
- Other responders are also present in the network

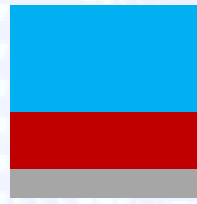


Performance Metrics



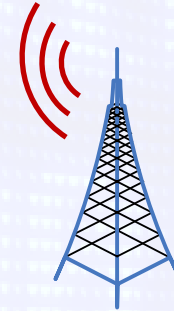
Signal,
Reference Signal
Received Power
(RSRP)

Interference
Noise

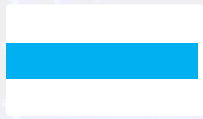


USER

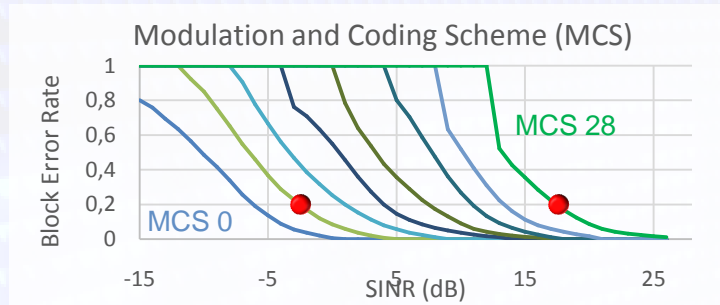
Signal to Interference
plus Noise Ratio (SINR)



Resource Blocks (RBs) needed
to transmit packet



SINR



Transmission Bandwidth
(50 RBs for 10 MHz)

Does user
packet have
enough RBs?

YES

USER
COVERED

THROUGHPUT /
USER

NETWORK
THROUGHPUT

NO

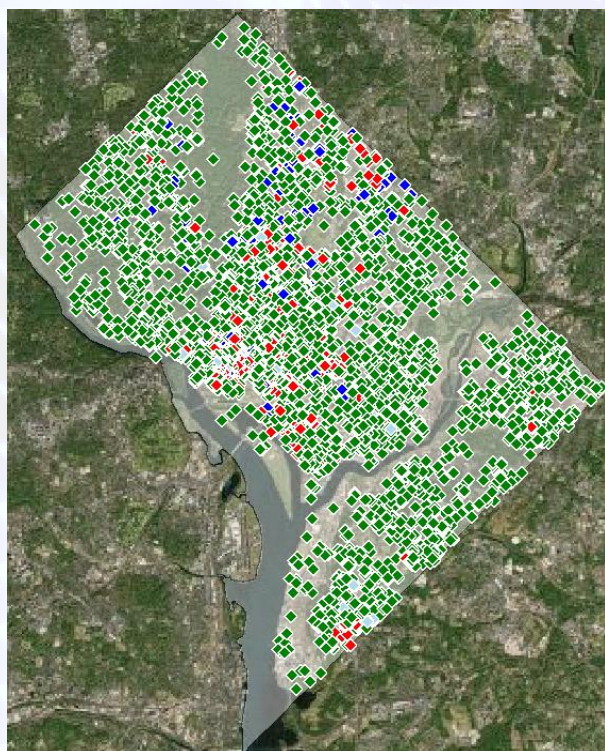
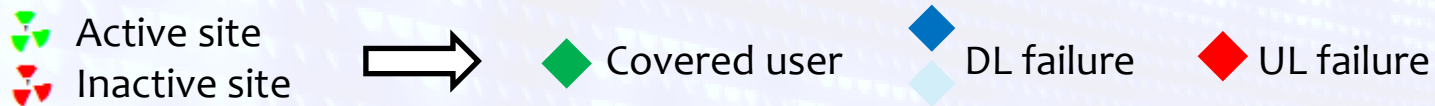
USER NOT
COVERED

Outages in Typical LTE Deployments

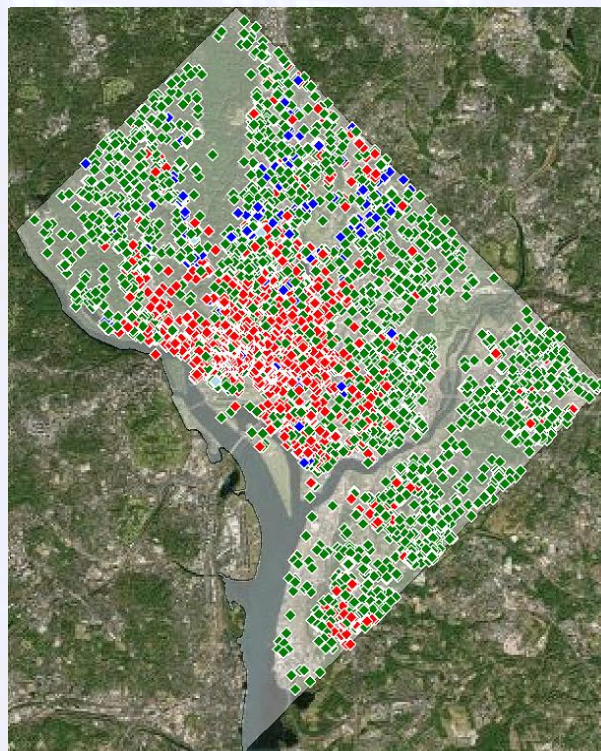
Baseline Results

How Users Experience Outages Today

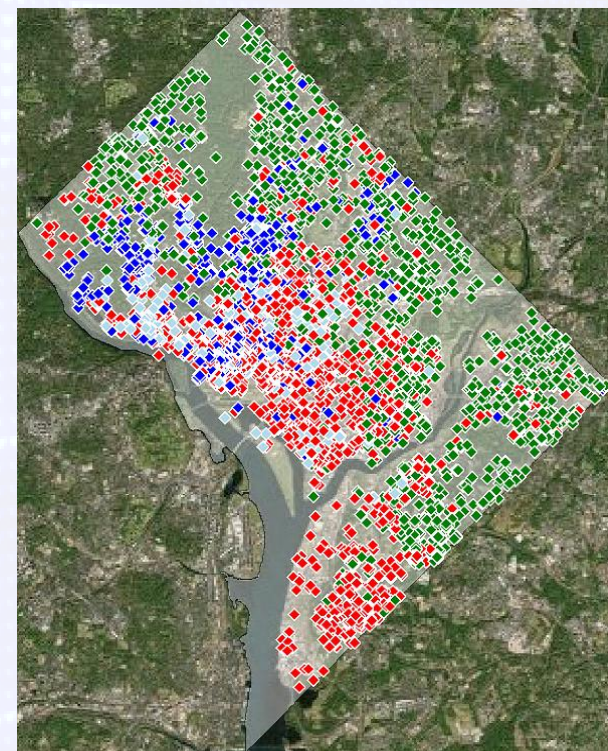
Localized Outages



Outage 10% → Coverage 83%



Outage 30% → Coverage 60%

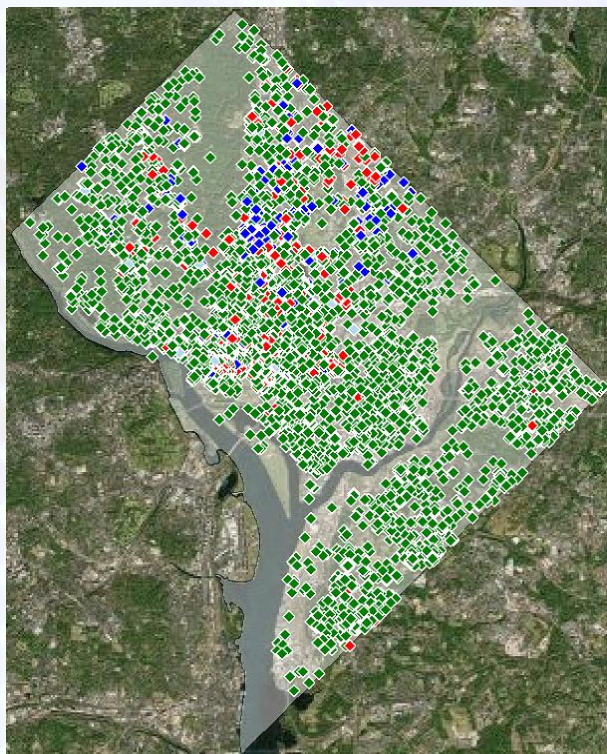
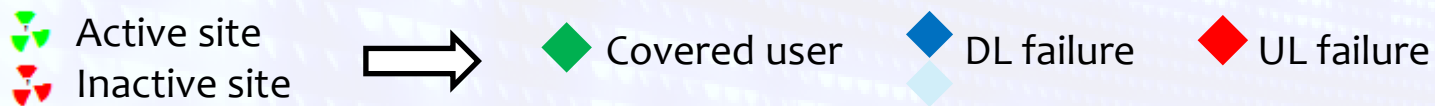


Outage 60% → Coverage 33%

- In localized outage, the inactive sites are concentrated in one area of the city
- The coverage failures surround the inactive sites

How Users Experience Outages Today

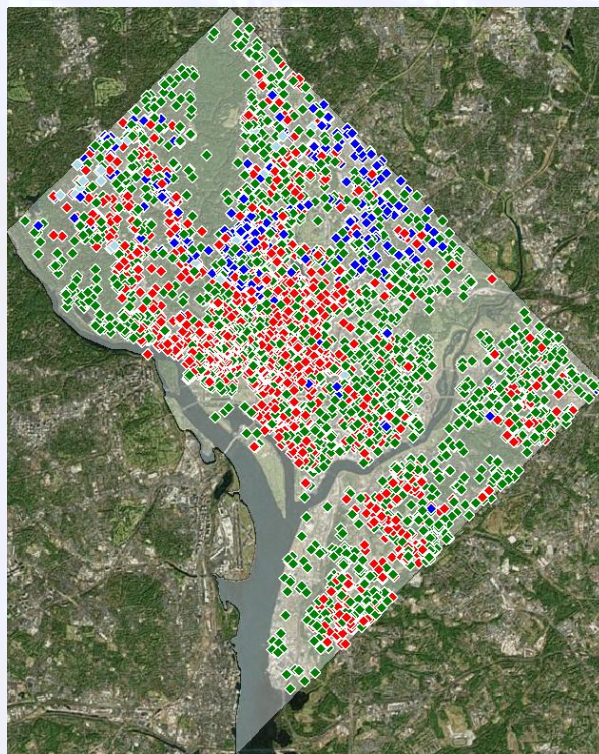
Random Outages



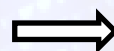
Outage 10%



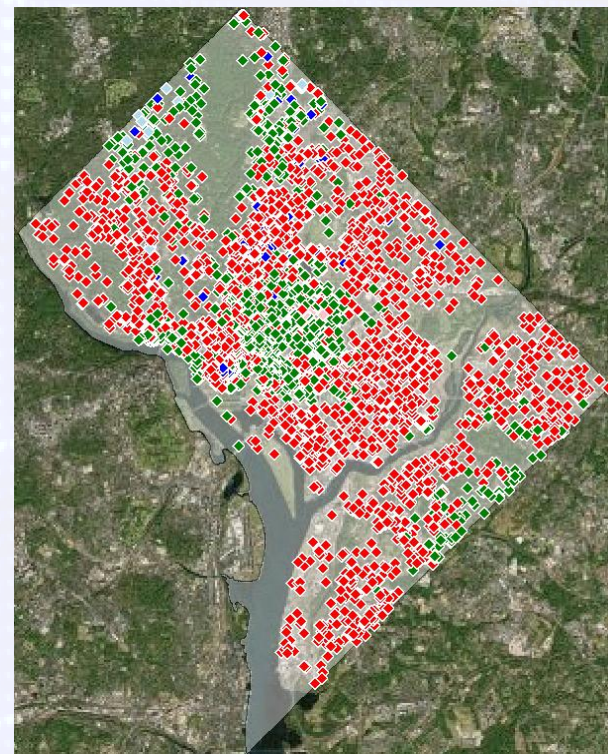
Coverage 84%



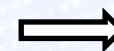
Outage 30%



Coverage 55%



Outage 60%

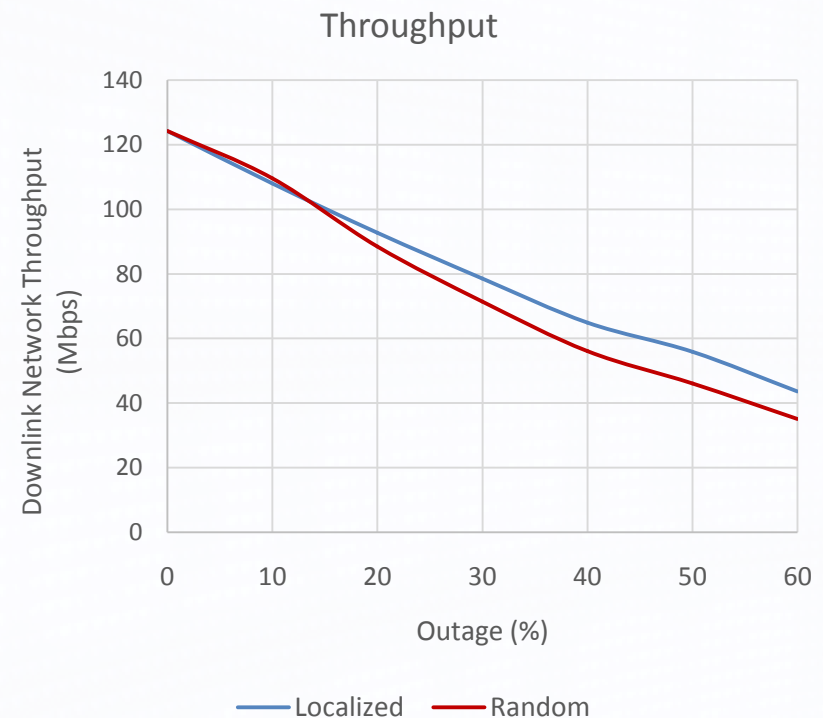
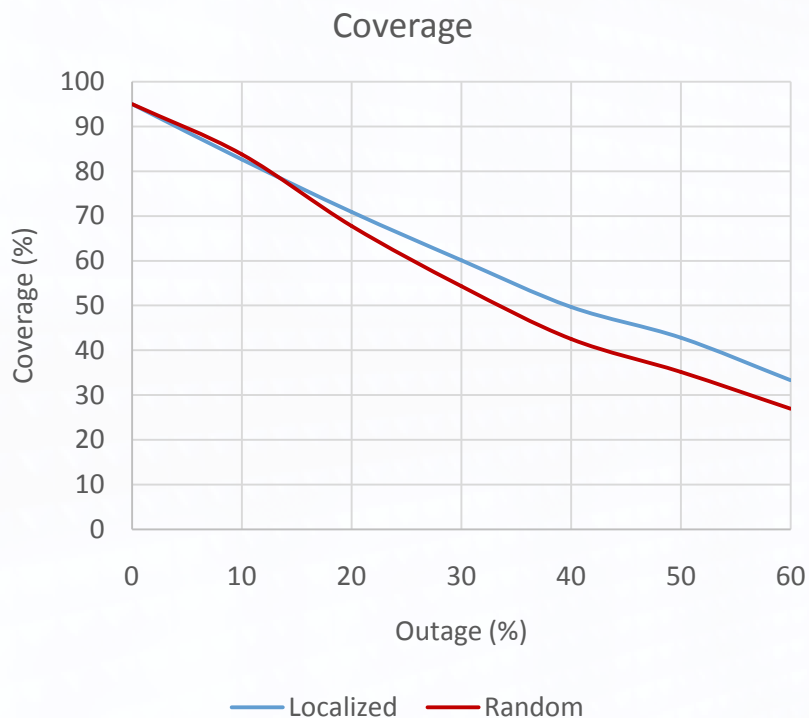


Coverage 28%

- In random outage, the inactive sites are distributed throughout the city
- As for the localized case, higher outage translates into lower coverage

Coverage and Throughput

Baseline



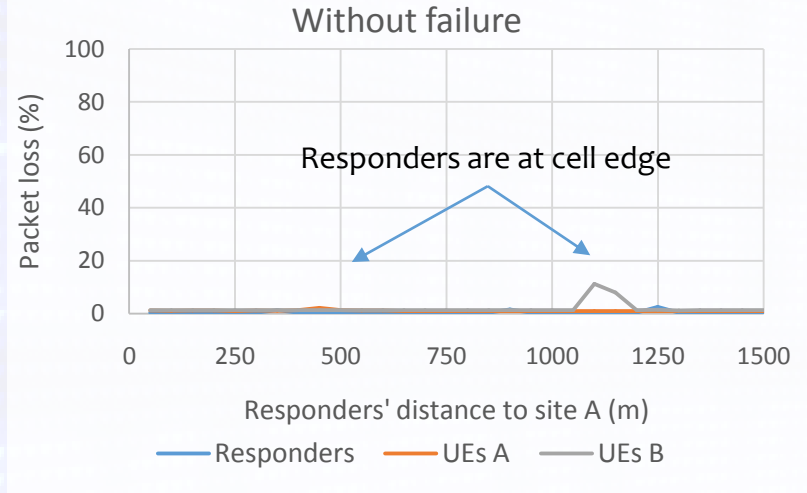
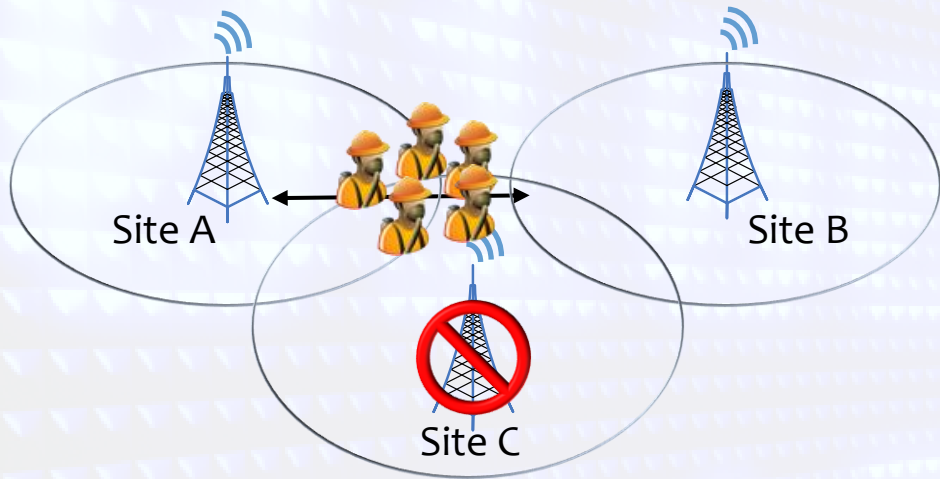
- Although the outage topologies are different, the resultant coverage and throughput are comparable.



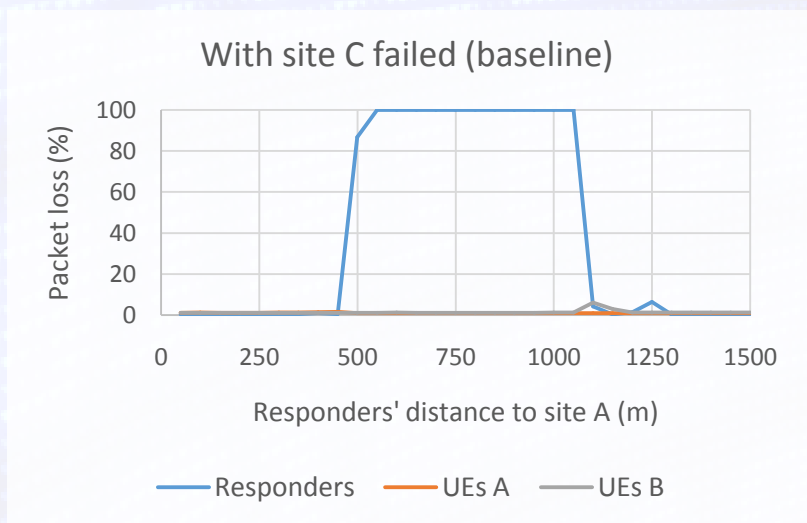
⇒ How to maintain coverage during outages?

Packet Loss

Baseline

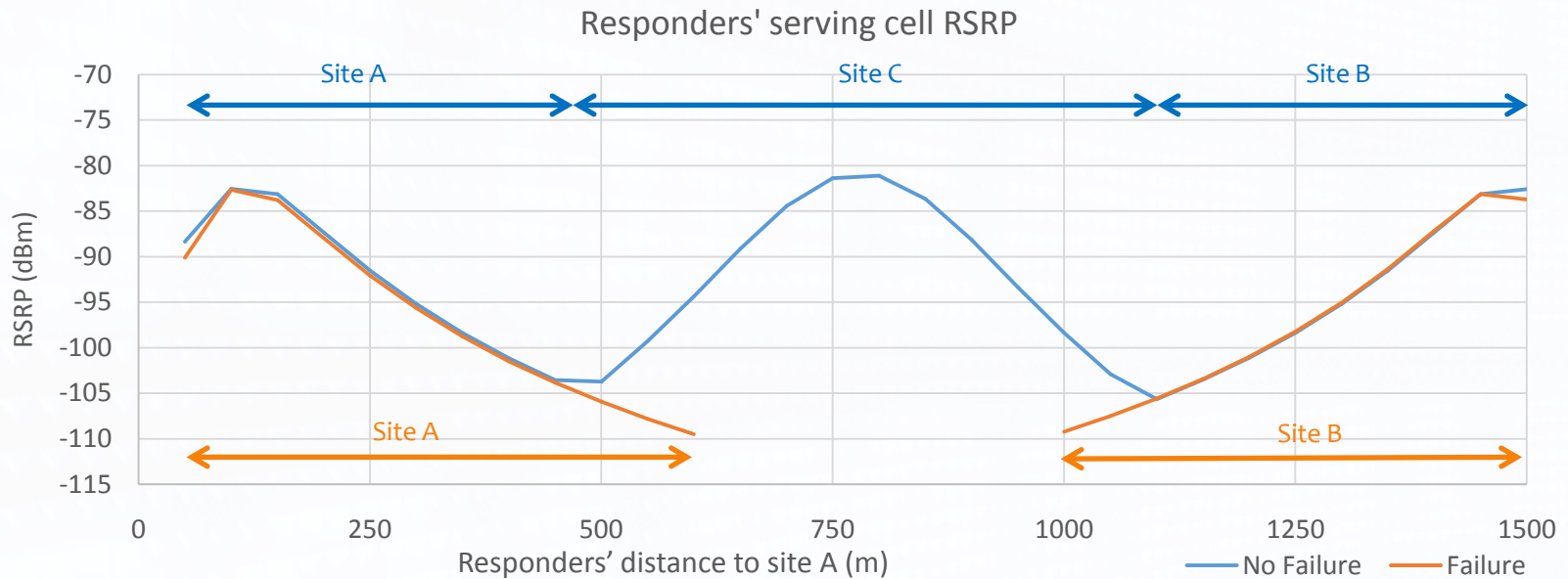


- With all sites active, packet loss is observed when responders are at the cell edge.
- When Site C is failed, the responders experience a total loss of connectivity (100 % packet loss)
 - The coverage gap is 500 m



Reference Signal Received Power

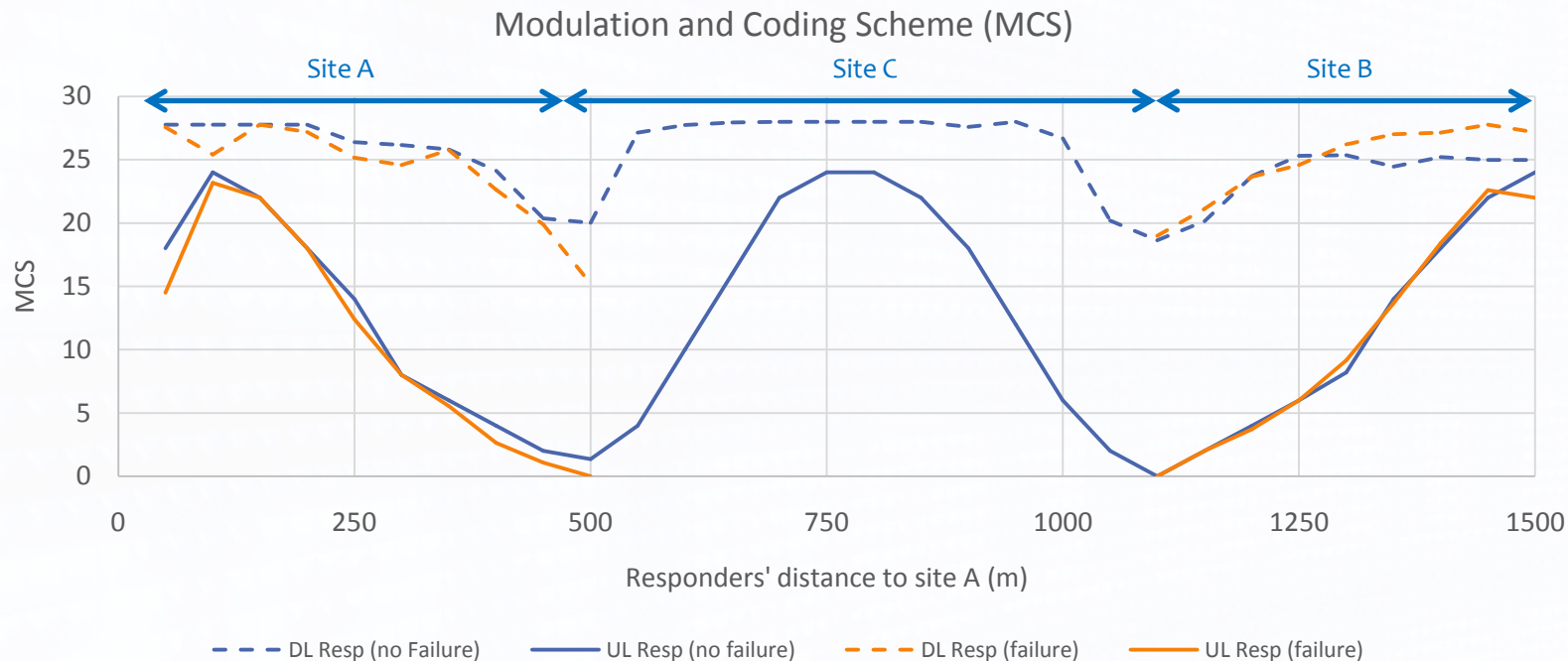
Baseline



- The RSRP increases when the responders are located between 100 m and 200 m due to higher antenna gain
- When site C is failed, the responders try to stay on the remaining sites as long as possible
- When the responders are located between 650 m and 950 m from site A, the responders are not able to detect and connect to any site

Modulation Coding Scheme

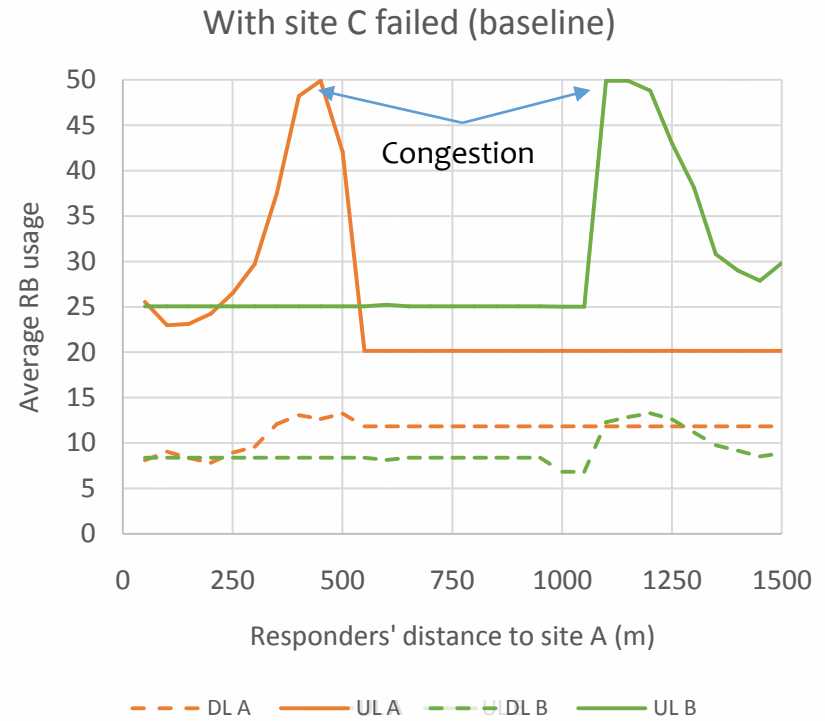
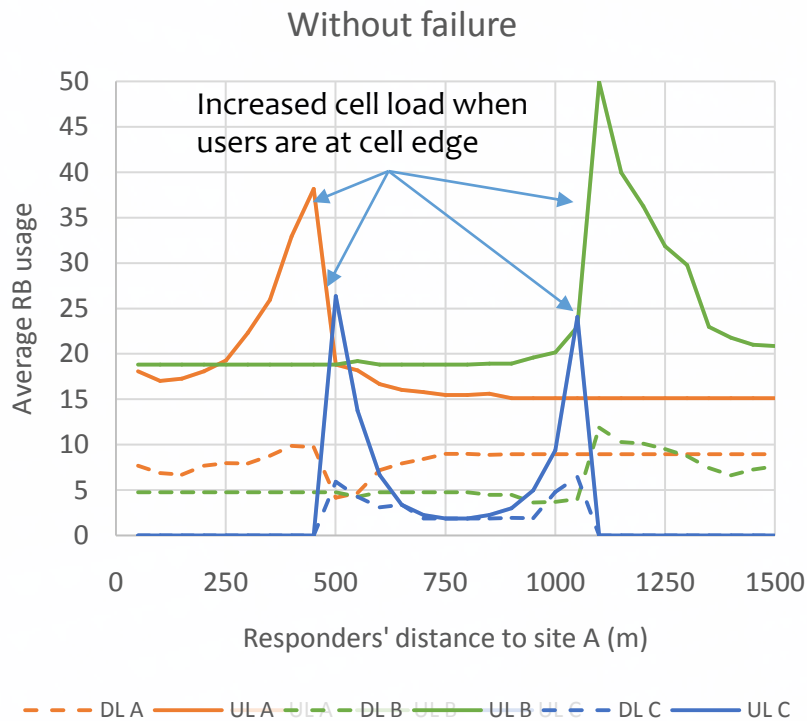
Baseline



- As responders move away from site A, the quality of the signal degrades
 - A lower SINR triggers the use of a lower MCS
 - More resource blocks are needed to carry the responder traffic
- The uplink MCS is degrading much faster than the downlink indicated an uplink-limited network

Resource Block Usage

Baseline



- When responders are at the edge of a cell, their lower MCS causes an increase in the RBs utilization
- During Site C failure, the number of RBs used reached its maximum value
 - Congestion occurs where there are no RBs available

Traffic Control



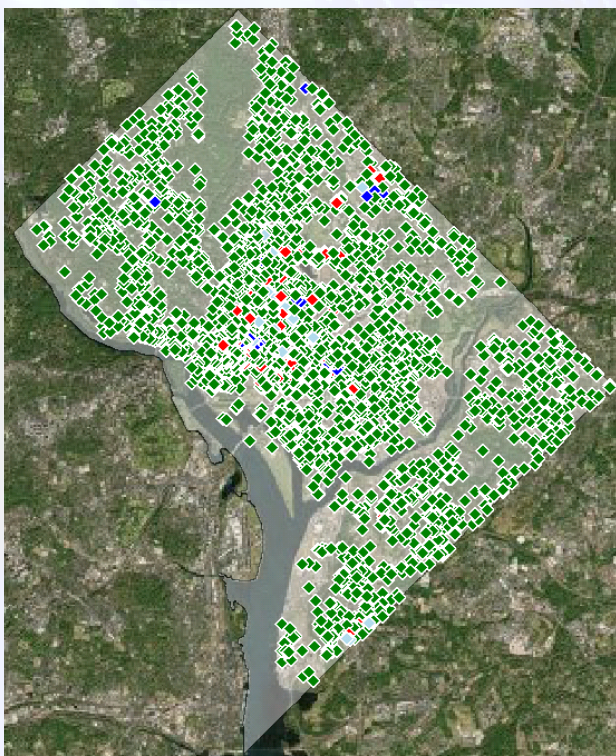
Traffic Control Strategy

- ▣ The basic idea consists of trading capacity for coverage during an outage in order to maintain connectivity
- ▣ By limiting the traffic admitted on the public safety network it may be possible to mitigate site failures and maintain target coverage. Ways to implement traffic control include:
 - ▣ Data rate adaptation
 - ▣ Priority and preemption
- ▣ Given an outage percentage and a user coverage target, the traffic control strategy is to throttle the traffic demand in order to meet the target coverage
- ▣ The implementation of this strategy in response to failures may be achieved based on predetermined coverage and capacity targets

Coverage Maps

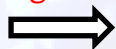
Baseline vs. Traffic Control

◆ Covered user ◆ DL failure ◆ UL failure

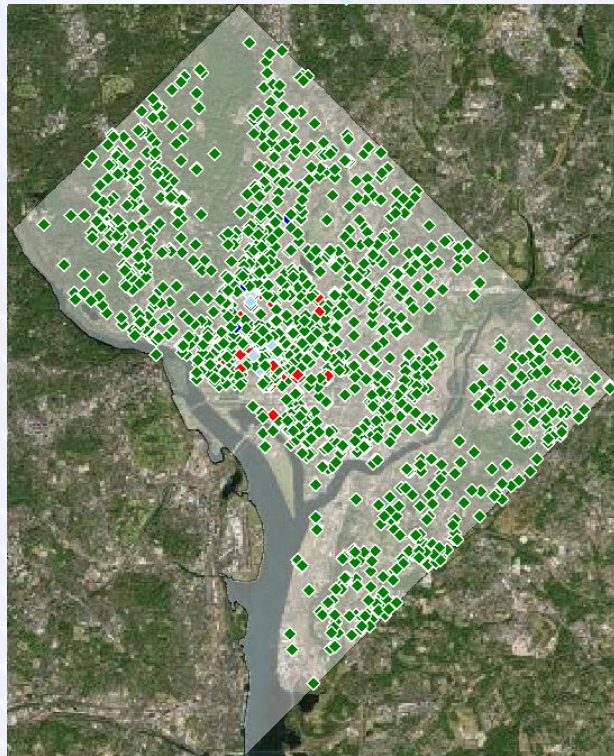


Outage 10%

Coverage 84%

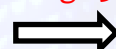


Coverage 95%

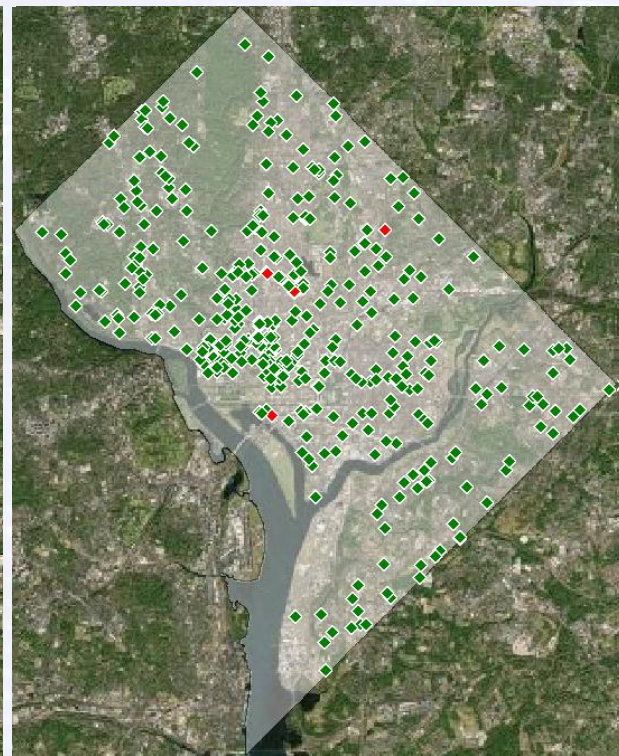


Outage 30%

Coverage 60%

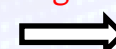


Coverage 95%



Outage 60%

Coverage 33%



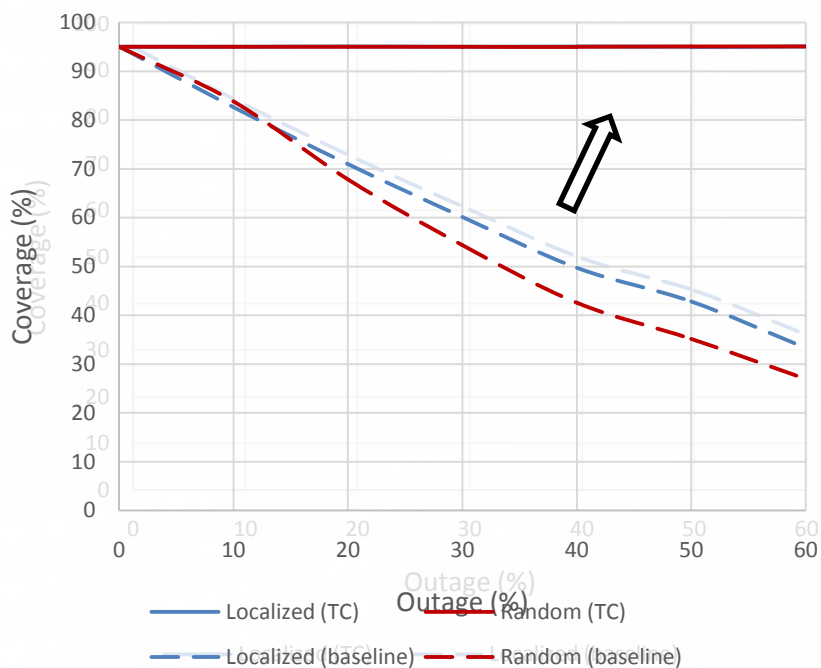
Coverage 95%

- By reducing the traffic demand, coverage can be restored to 95%
- Although the outage increases, the coverage now remains fixed
- Increased coverage comes at the expense of reduced throughput

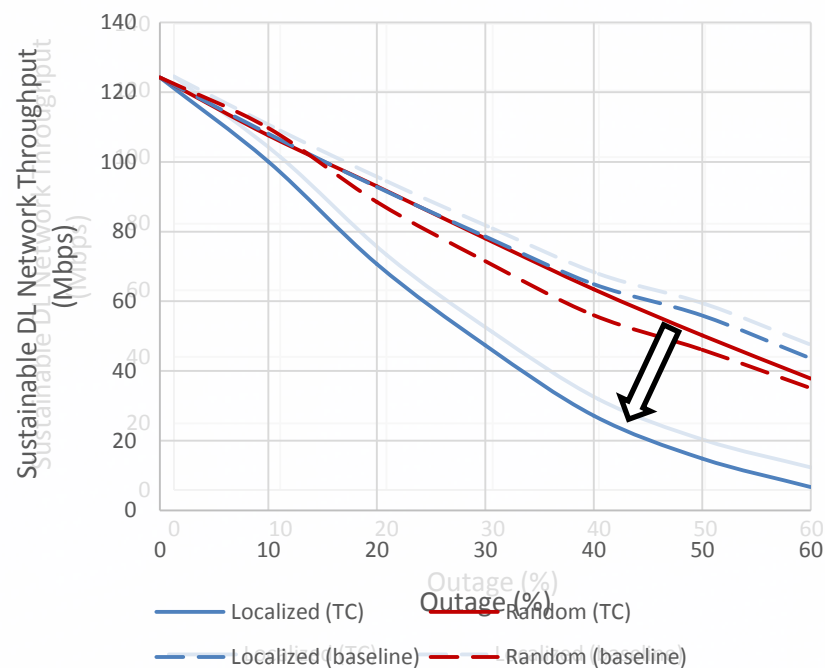
Coverage and Throughput

Baseline vs. Traffic Control

Coverage



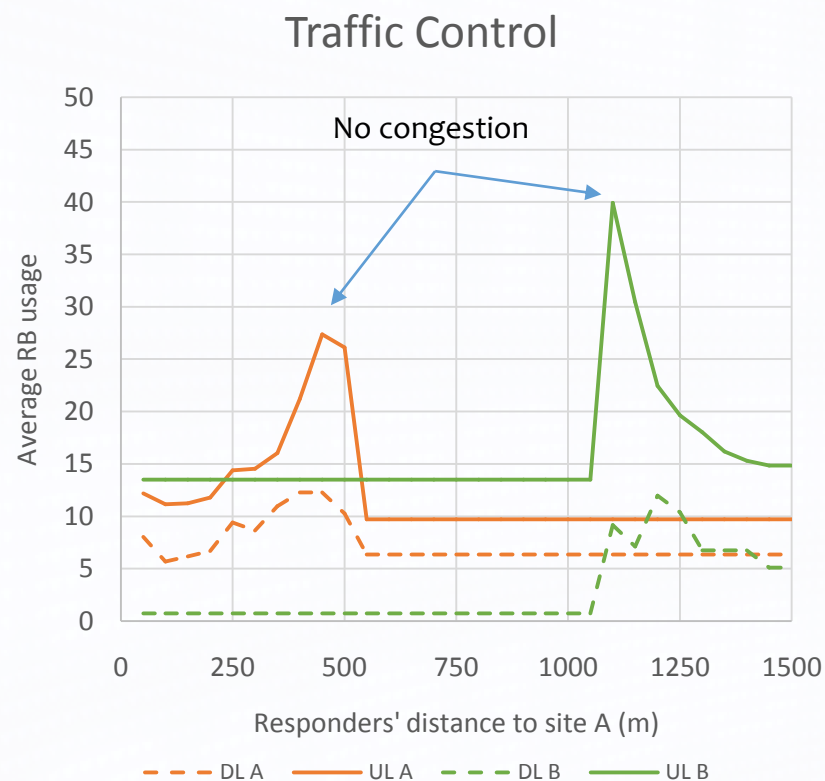
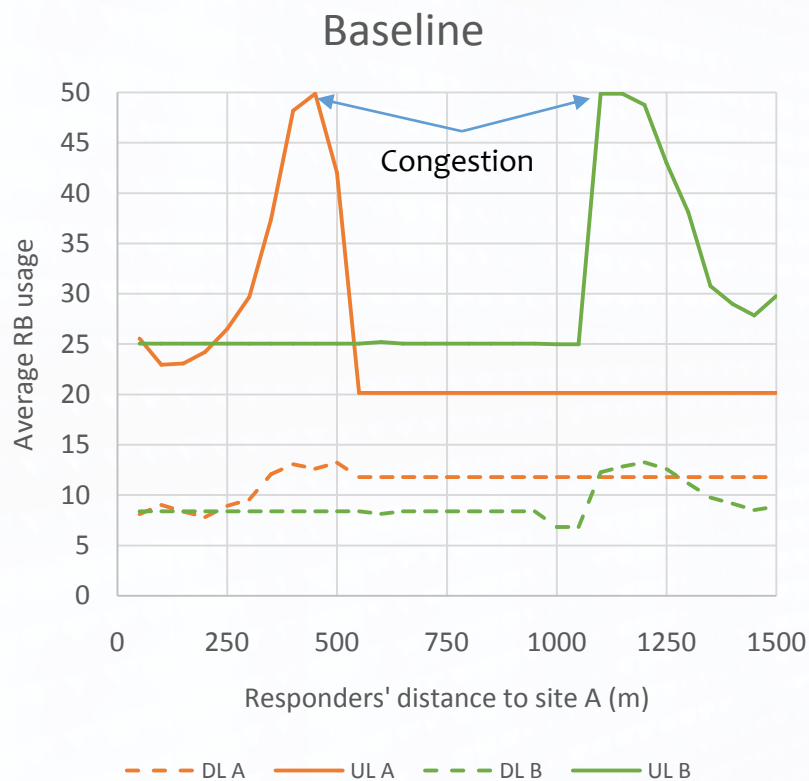
Throughput



- With traffic control, coverage can be restored to 95% **across all outages**, but the sustainable network throughput can drop significantly
- The results are similar for random outage, but the drop in throughput is less since the outage topology is less severe

Resource Block Usage

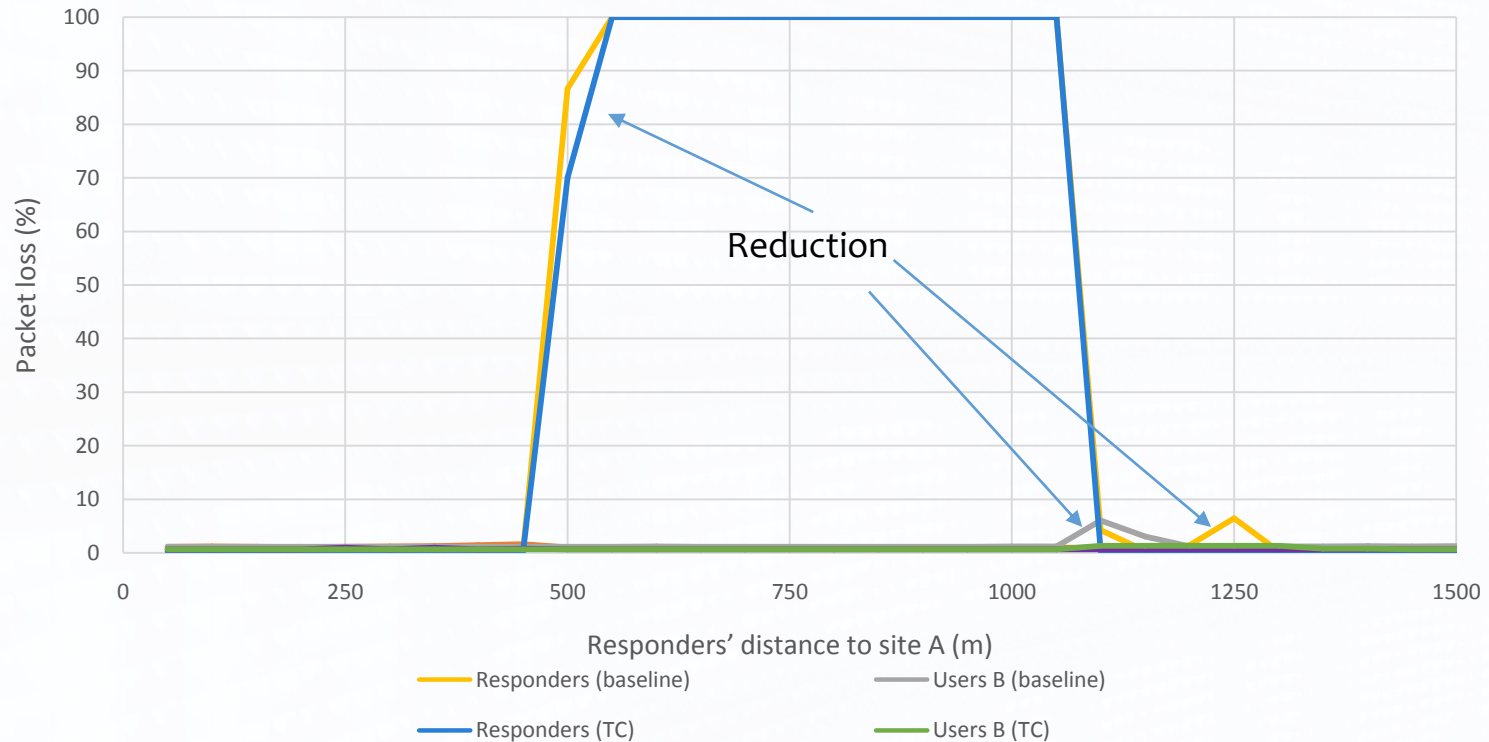
Baseline vs. Traffic Control



- The results shown are based on a 50% traffic reduction for all users
- Congestion is experienced when the resources-block usage is saturated at 50
- Reducing the traffic in the network reduces the usage, eliminating congestion even when the responders are at cell edge

Packet Loss

Baseline vs. Traffic Control



- The drop in resource block-usage in turn reduces packet loss
- The coverage gap for the responders is not reduced
- The network is no longer capacity-limited in the uplink, but coverage-limited

High-power UE



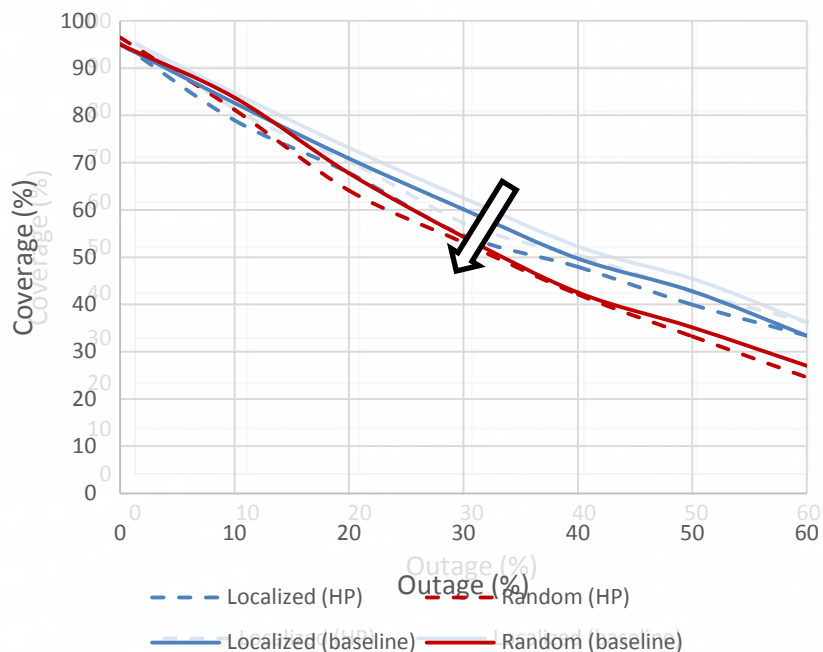
High-power UE Strategy

- Another strategy to maintain connectivity during an outage is to use higher power for UE transmission
- The high-power strategy consists of increasing the transmitted power from the baseline value of 0.2 W to the high-power value of 1.2 W to improve the coverage footprint
- However, with higher transmitted power comes increased interference

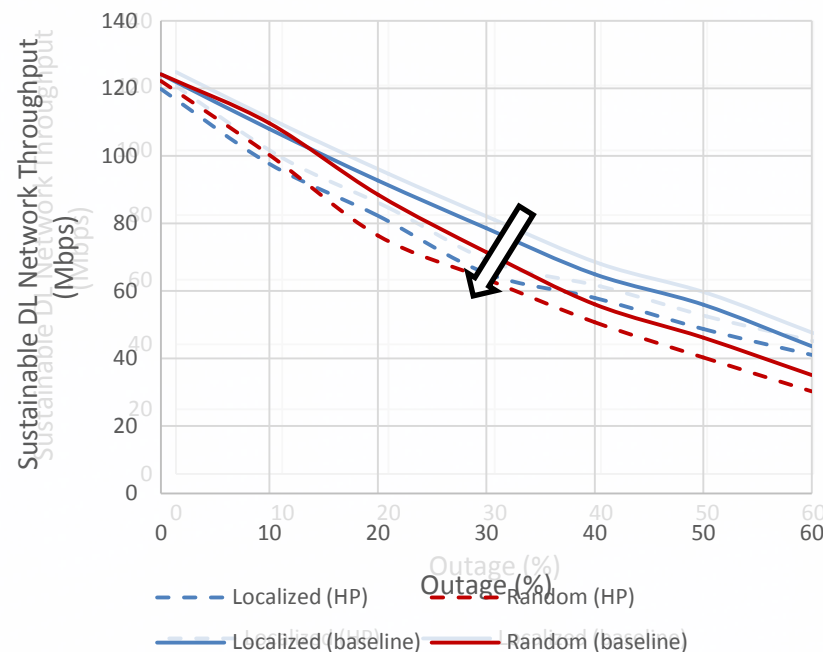
Coverage and Throughput

Baseline vs. High-power UE

Coverage



Throughput

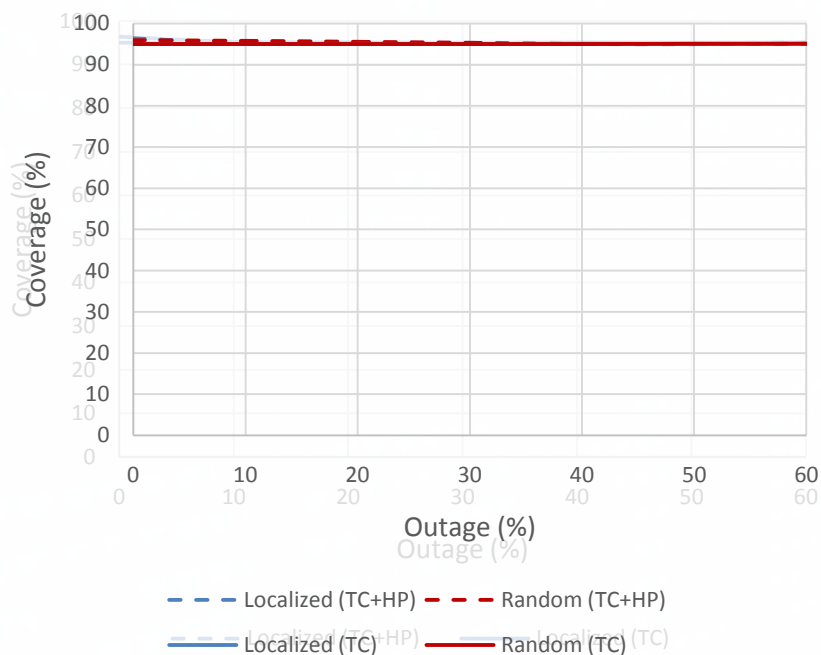


- Transmitting at higher power may not always be beneficial due to the increased interference it creates
- In a more comprehensive study, we have found higher power to be beneficial in rural areas where traffic is low and the opposite in urban areas where it is high

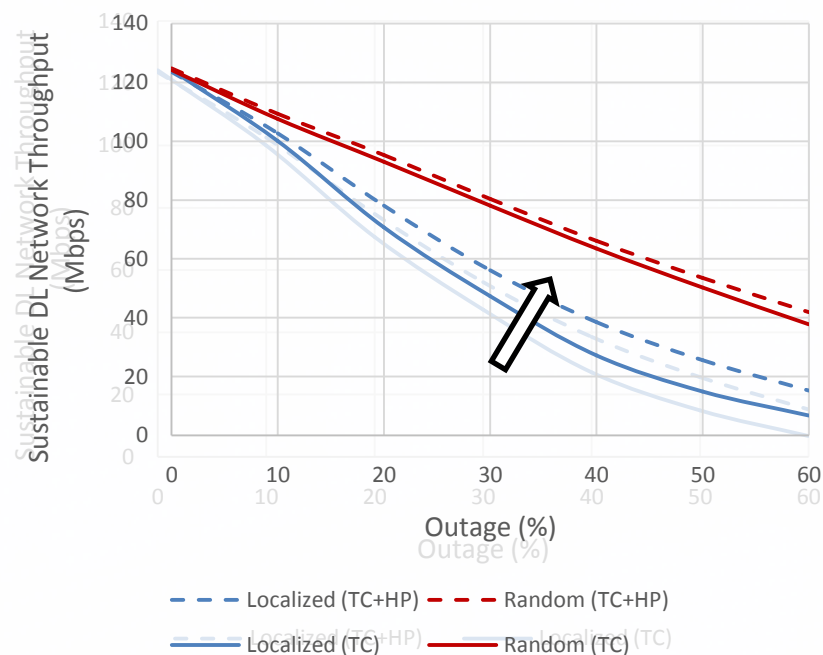
Coverage and Throughput

Traffic Control vs. Traffic Control + High-power UE

Coverage



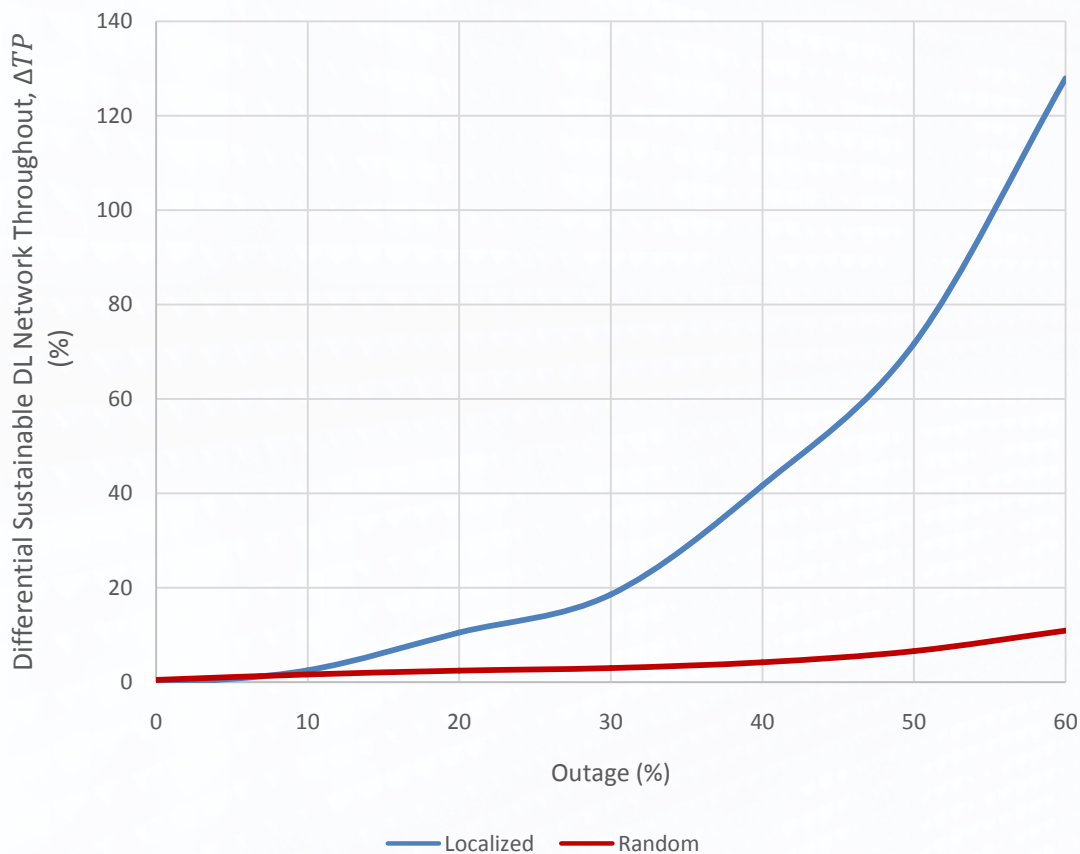
Throughput



- When combined with traffic control, which limits uplink interference, high-power transmission can be more effective in restoring throughput
- High-power transmission is most effective when outage is severe:
 - Localized outage
 - High outage percentages

Throughput Improvements

Traffic Control vs. Traffic Control + High-power UE

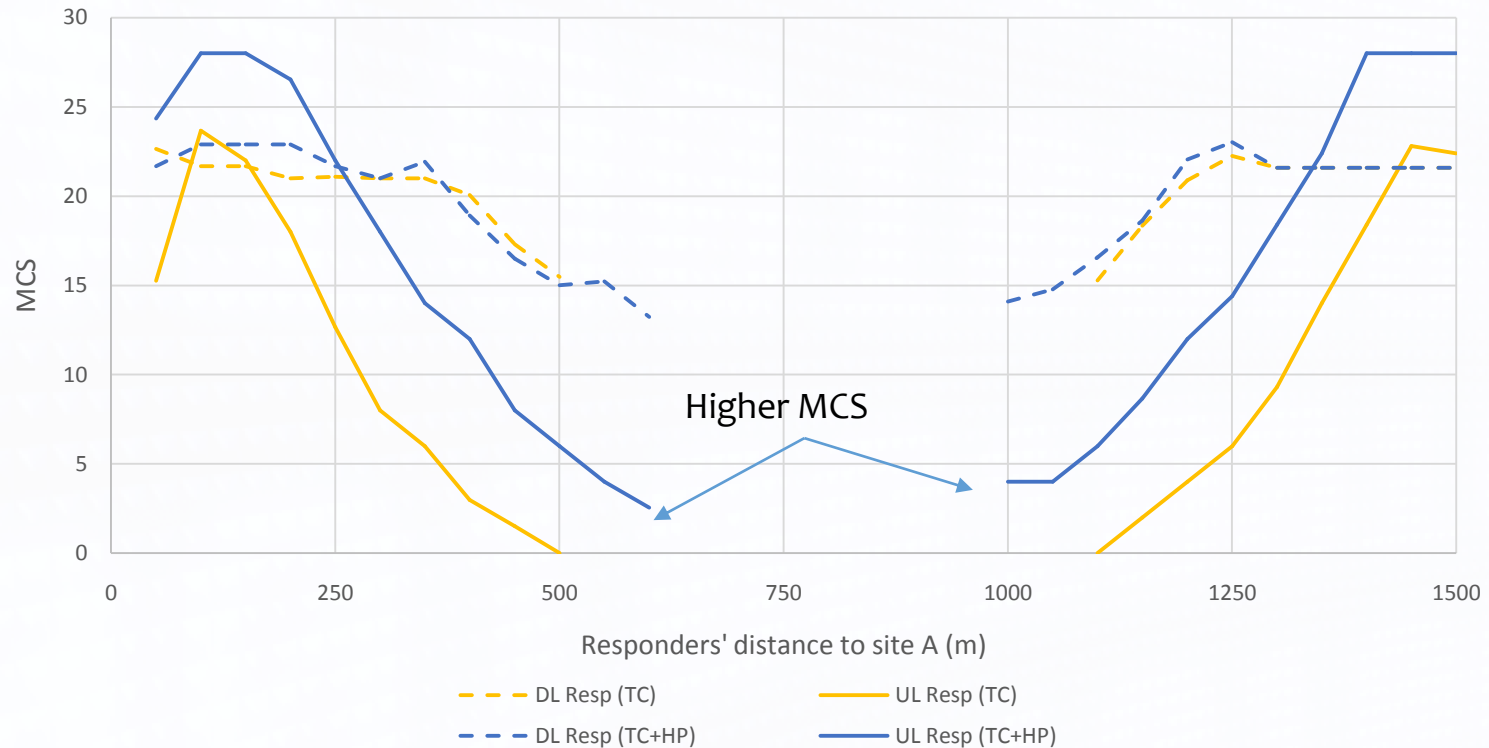


$$\Delta TP = \frac{\text{Increase in TP using 1.2 W}}{\text{TP using 0.2 W}}$$

- With traffic control, the increase in throughput using the 1.2 W UE can be as great as 130%

MCS

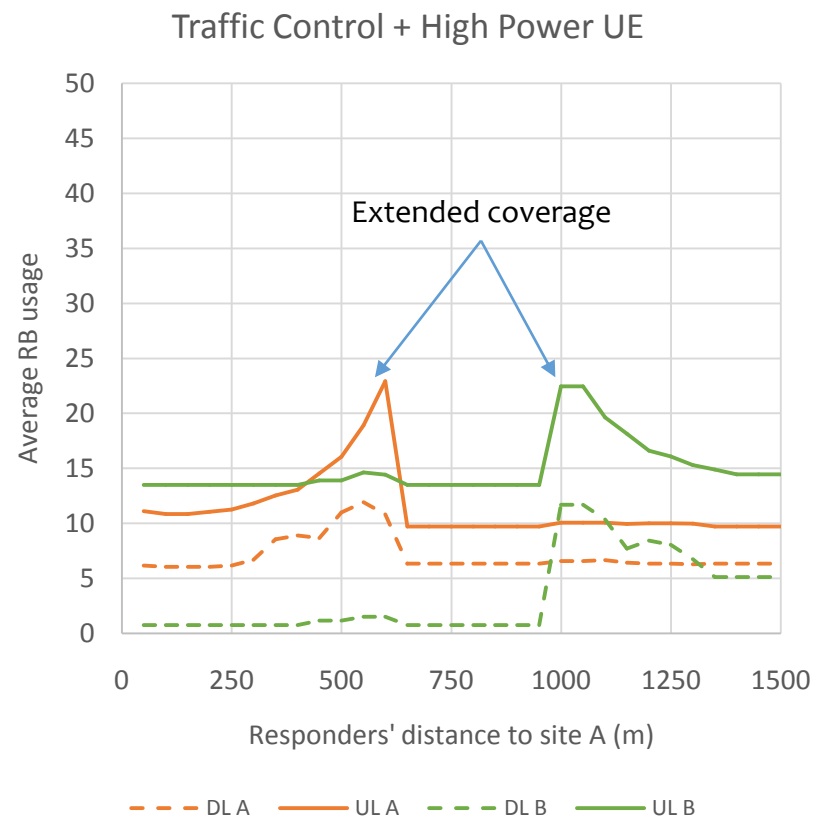
Traffic Control vs. Traffic Control + High-power UE



- Higher power provides better uplink SINR for the responders, allowing for more efficient MCS and increased capacity

Resource Block Usage

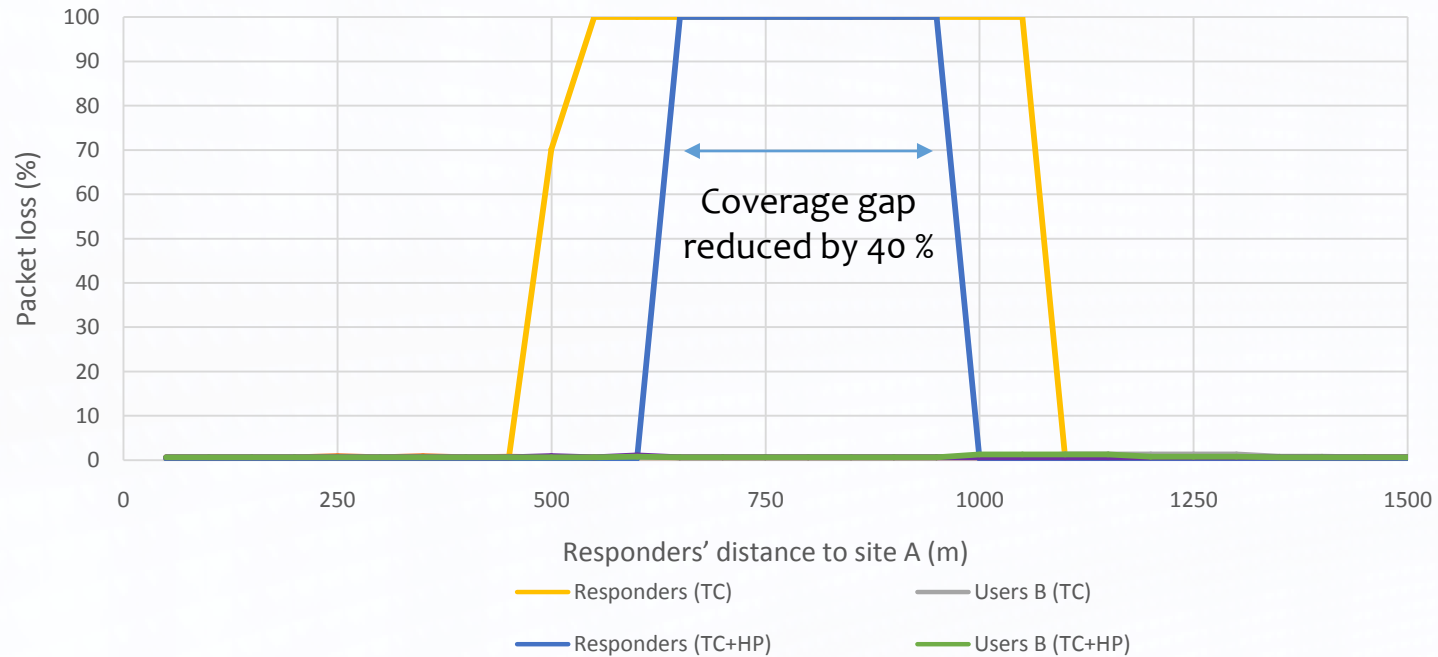
Traffic Control vs Traffic Control + High-power UE



- Higher MCS in the uplink leads to lower resource-block usage
- Higher-power UE provides extended coverage on the uplink

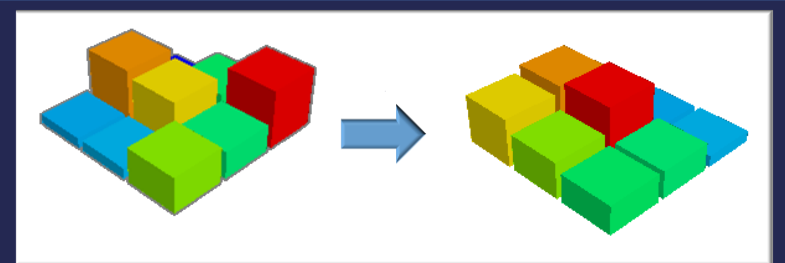
Packet Loss

Traffic Control vs. Traffic Control + High-power UE



- Extended coverage on the uplink reduces the coverage gap by 40%
- The network is no longer uplink-limited, but downlink-limited due to lack of reference coverage

=> Can this coverage gap be reduced further?



Parameter Configuration

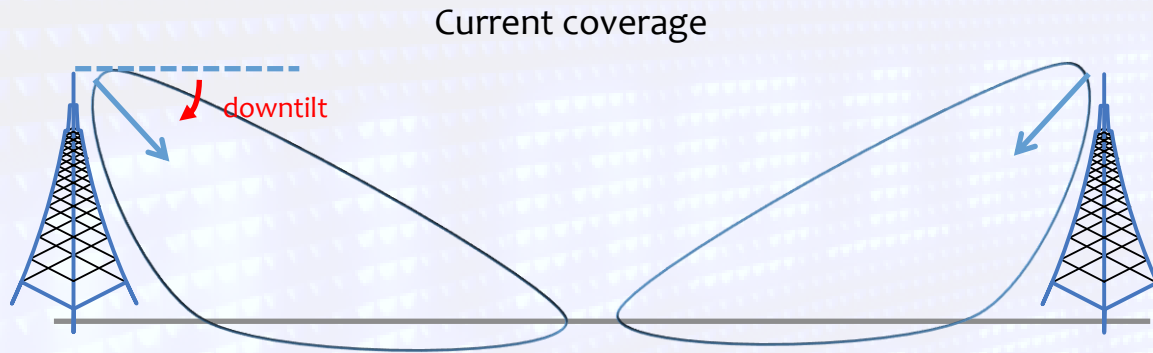
LTE support for Self Optimizing Networks

- Self Optimizing Networks (SONs) are defined by the automation of the planning, configuration, and optimization of the network.
 - Reduces operational expenditure (OPEX) by reducing manual configuration of network elements
 - Speeds up network recovery

- LTE standardized key functions/interfaces to support multi-vendor SON solutions in three main categories:
 - Self-Configuration
 - Enable cell to self-configure its Physical Cell Identity, transmission frequency and power
 - Automatic Neighbor Relations (ANR)
 - Dynamic configuration of S1 and X2 interfaces, IP address and IP backhaul
 - Self-Optimization
 - Mobility Load Balancing (MLB)
 - Mobility Robustness Optimization (MRO)
 - Energy Saving.
 - RACH optimization to minimize number of attempts on the PRACH causing interference
 - Inter-cell interference coordination (ICIC)
 - Self-Healing
 - Coverage and Capacity Optimization (CCO) due to cell failures
 - Cell outage detection and compensation
 - Minimization of Drive Tests (MDT) enables UEs to collect and provide RAN information from indoor and outdoor environments

Reconfiguration using Antenna Down Tilt

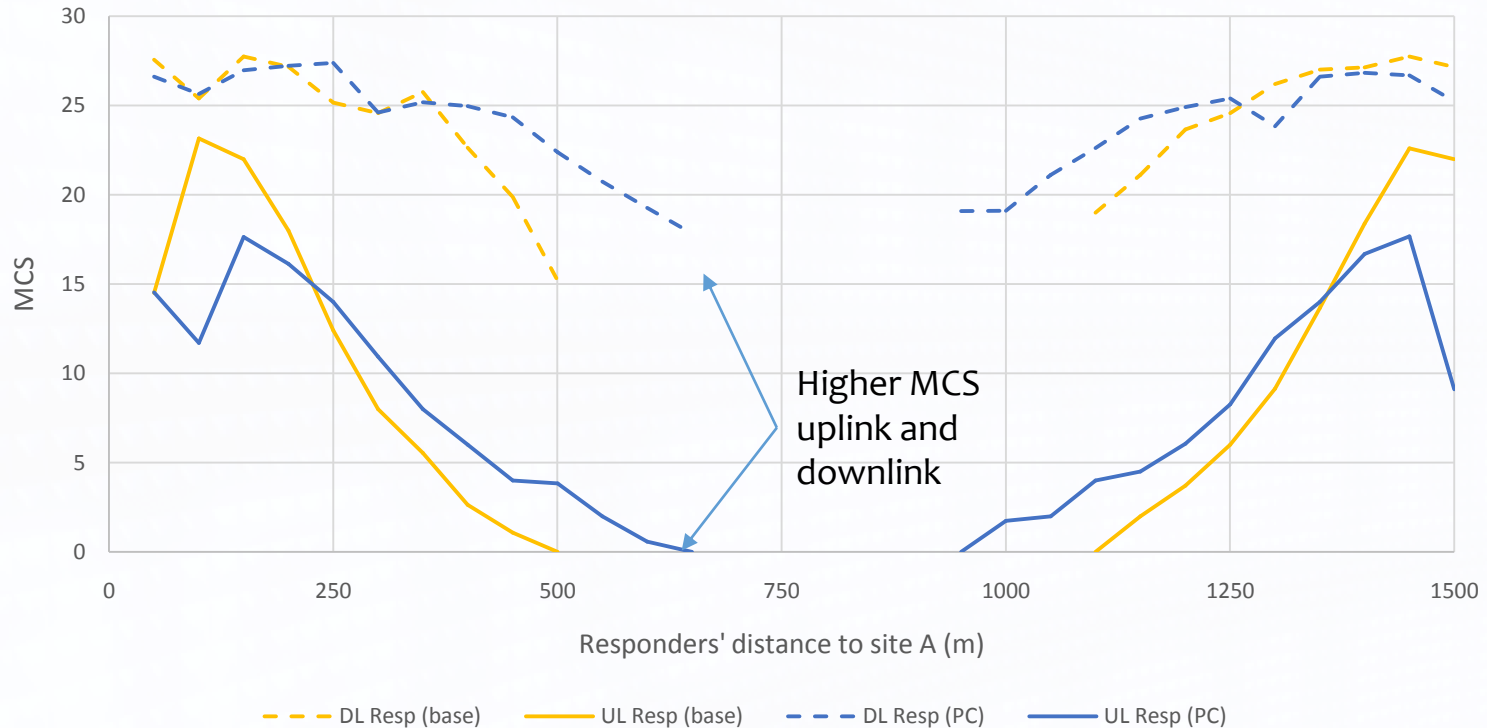
- ▣ The network coverage is affected by the site configuration
 - ▣ Azimuth, tilt, height, transmit power, etc...
- ▣ Some antennas, called Variable Electrical Tilt (VET) antennas are capable of modifying the radiation pattern without physically rotating the antenna. The operation can be performed remotely



- ▣ Changes made in our scenario:
 - ▣ Site A downtilt reduced from 10 degrees to 2 degrees
 - ▣ Site B downtilt reduced from 10 degrees to 5 degrees

MCS

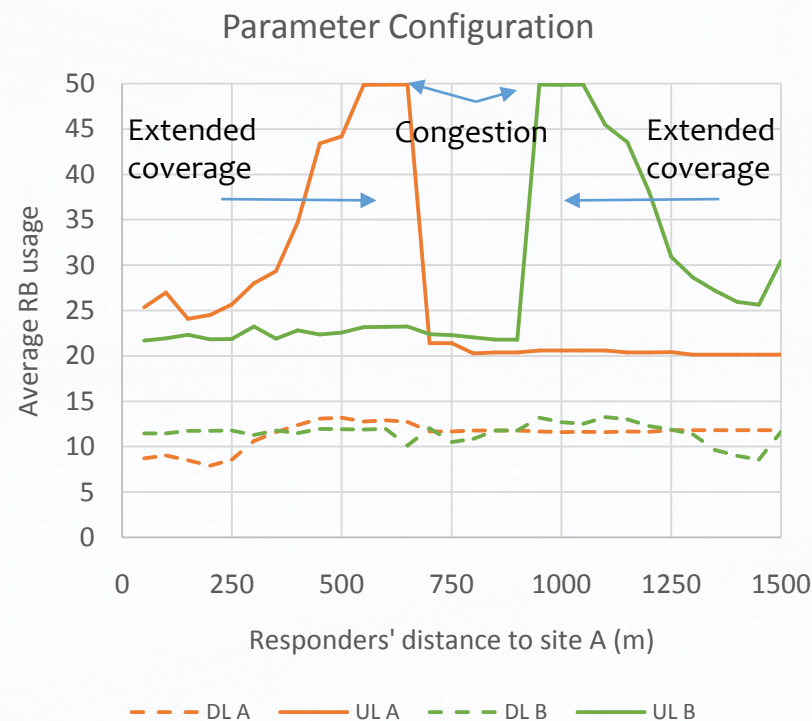
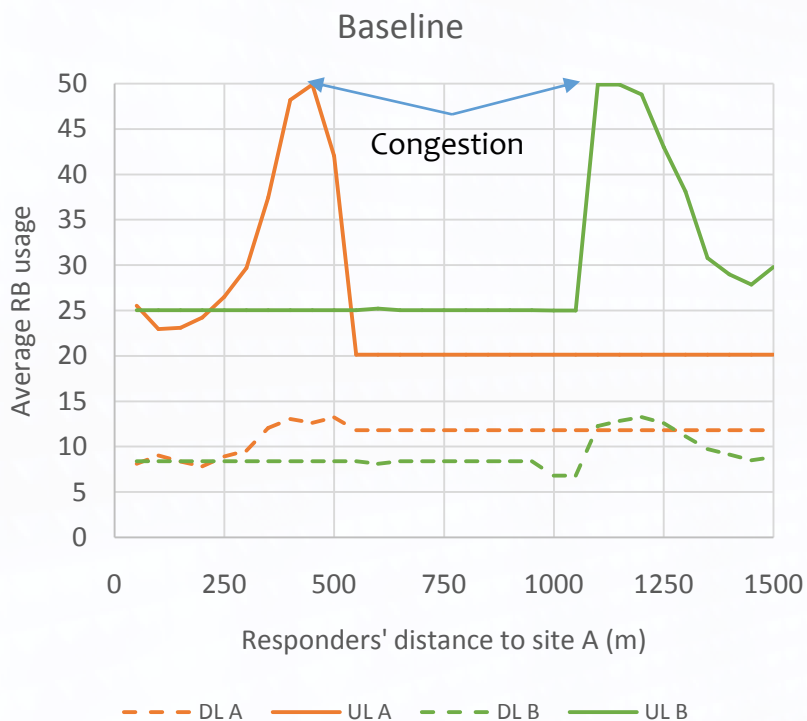
Baseline vs Parameter Configuration



- Changing the downtilt affects both the uplink and downlink
- While decreasing the downtilt increases coverage, areas near the cell are not performing as well due to the antenna pattern

Resource Block Usage

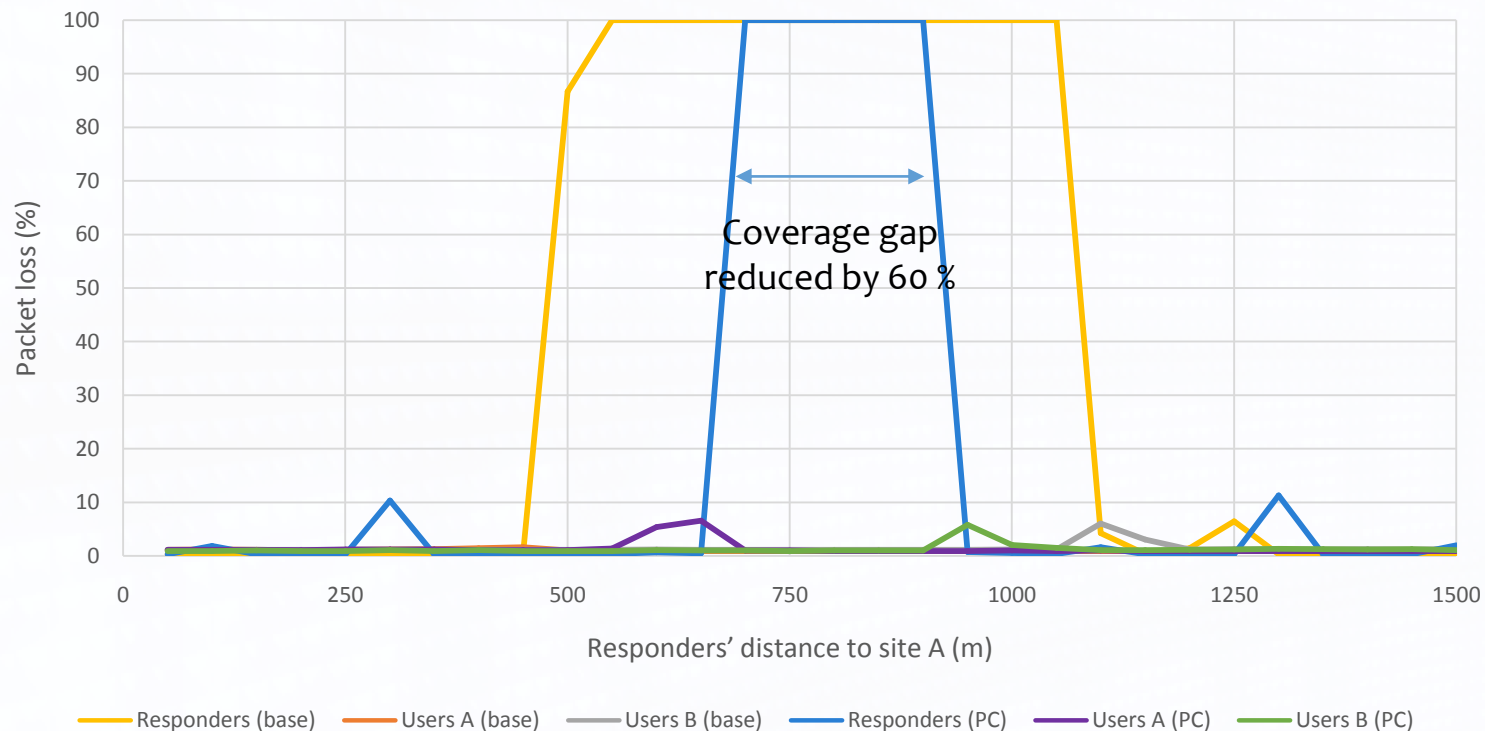
Baseline vs Parameter Configuration



- Coverage is increased but capacity is limited
- Congestion occurs when the responders are at the cell edge leading to packet loss

Packet loss

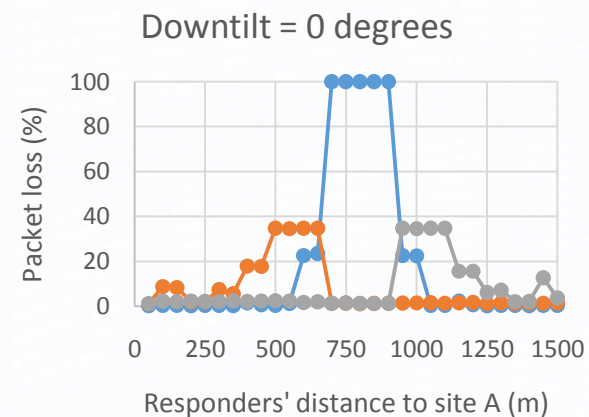
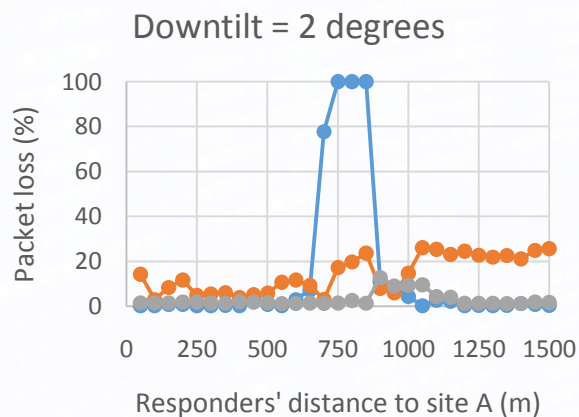
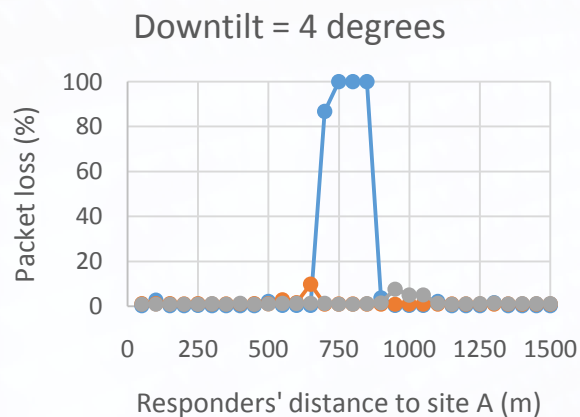
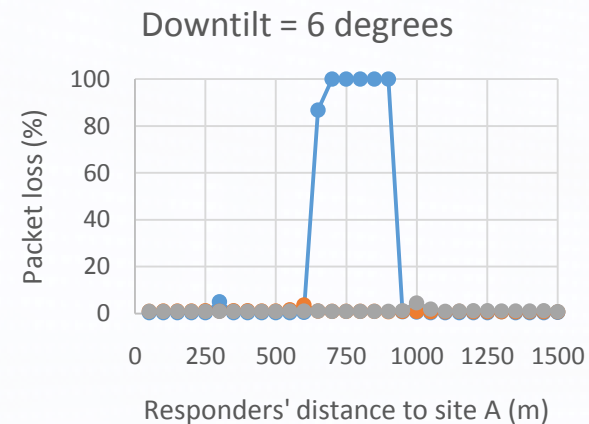
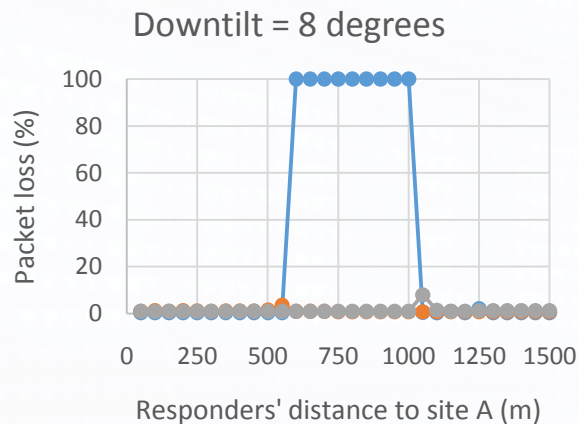
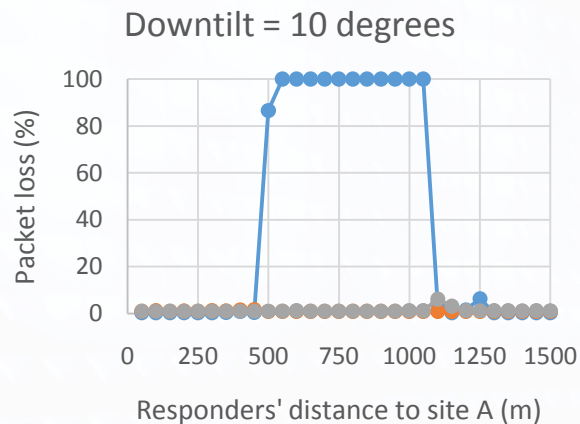
Baseline vs Parameter Configuration



- The coverage gap for the responders is reduced from 500 m to 200 m.
- While decreasing the downtilt increases coverage, areas near the cell are not performing as well due to the antenna pattern
- Some packet loss is observed at cell edge due to congestion

Impact of Downtilt on Packet Loss

Parameter Configuration



— Responders — UEs A — UEs B

— Responders — UEs A — UEs B

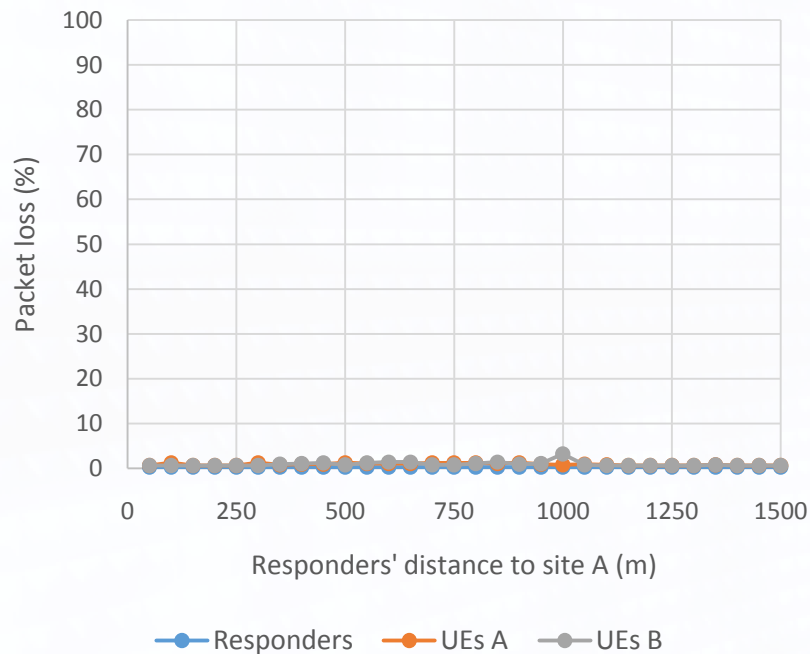
— Responders — UEs A — UEs B

- Network reconfiguration can improve or degrade the network performance
- Self optimization of the network requires coordination among cells

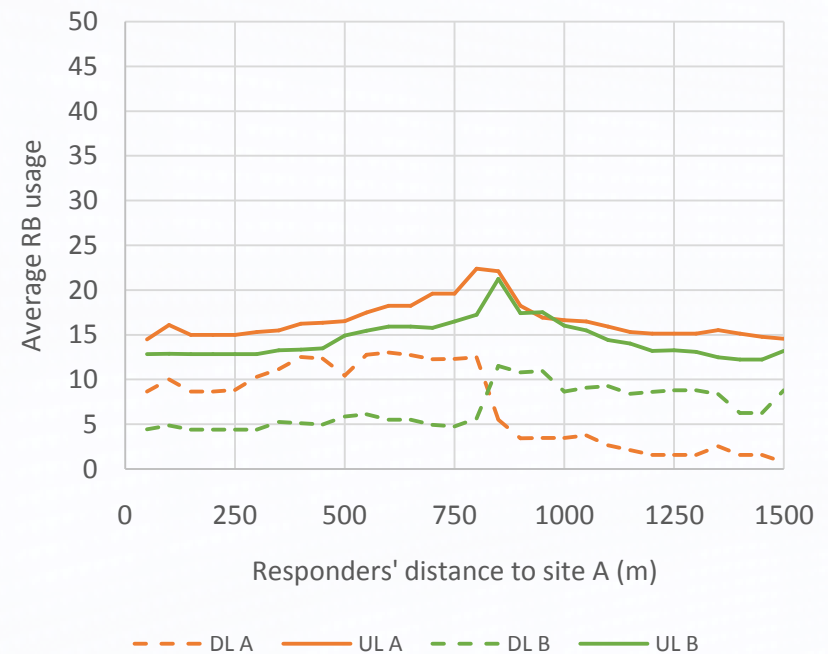
Packet Loss and Resource Block Usage

Traffic Control + High Power UE + Parameter Configuration

Packet loss



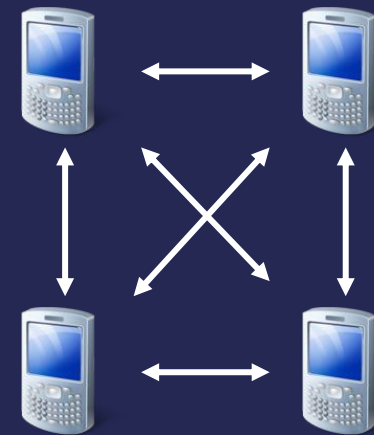
Resource Block Usage



- In our example, the combination of the traffic control, high power UE, and parameter configuration allowed the network to recover from a site outage

The responders are able to maintain connectivity regardless of their location

Device to Device

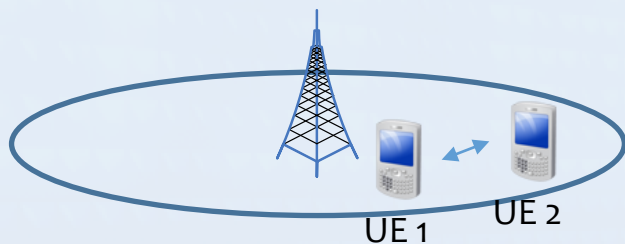


3GPP: Proximity Services (ProSe) Overview

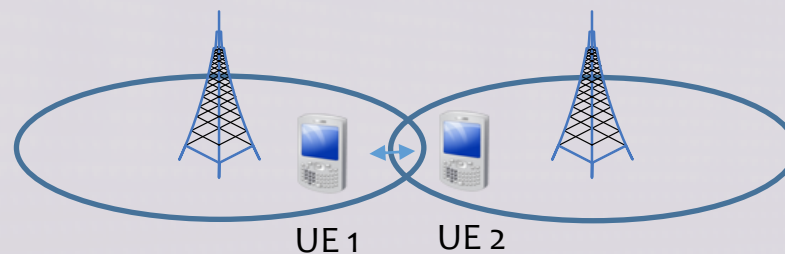
- Introduced to LTE in 3GPP Release 12
- The objective of ProSe is to enable Device-to-Device (D2D) communication services in nearby User Equipments (UEs)
- Services:
 - Discovery: The ability to detect the presence of another UE in proximity
 - Direct Communication: The capability to exchange user traffic without going through the eNodeB
- Potential Advantages
 - Spectrum utilization improvement
 - Improvement in overall throughput
 - Lower energy consumption in mobile devices

D2D Direct Communication Scenarios

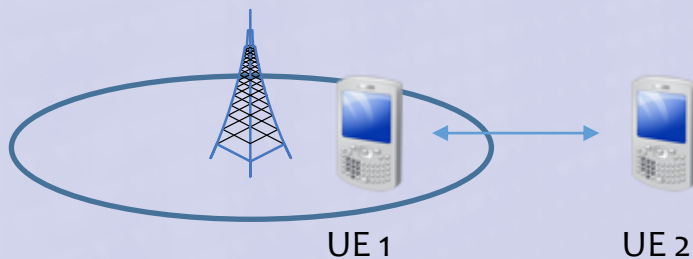
In coverage single cell



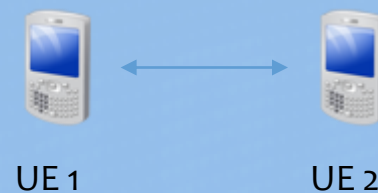
In coverage multiple cells



Partial Coverage



Out of coverage



3GPP: ProSe Features Defined in Release 12

The following subset of capabilities have been standardized in Release 12 (March 2015):

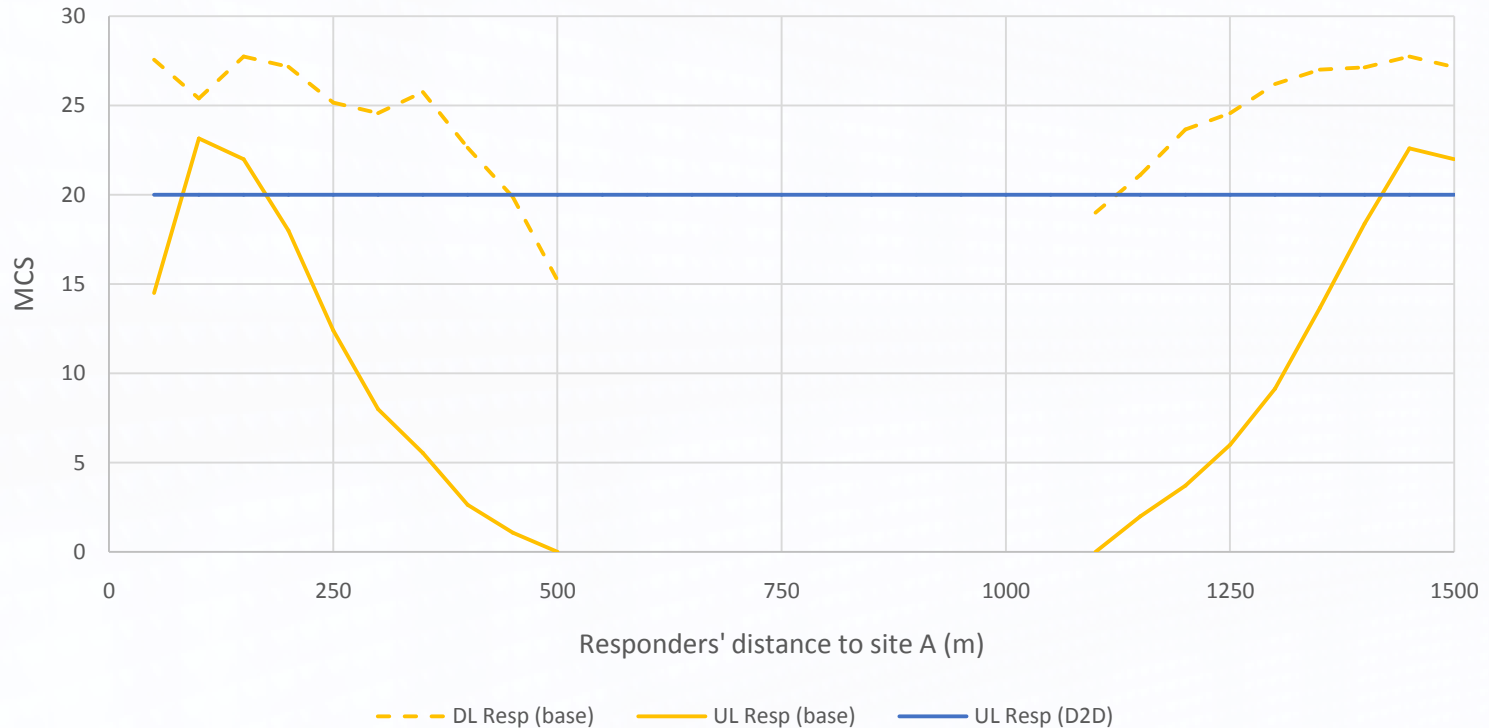
- ❑ Direct Discovery, only open discovery when UE is in coverage
- ❑ One-to-many communication for public safety using physical layer broadcast
- ❑ EPC-level discovery

Areas for further considerations:

- ❑ Lower spectral efficiency (64 QAM not allowed)
- ❑ Reliability (Fixed retransmissions with no feedback)
- ❑ No Quality of Service (QoS), no Priority
- ❑ Collisions in the resource pool when UEs select their own resources
- ❑ Limited resources/preconfiguration

MCS

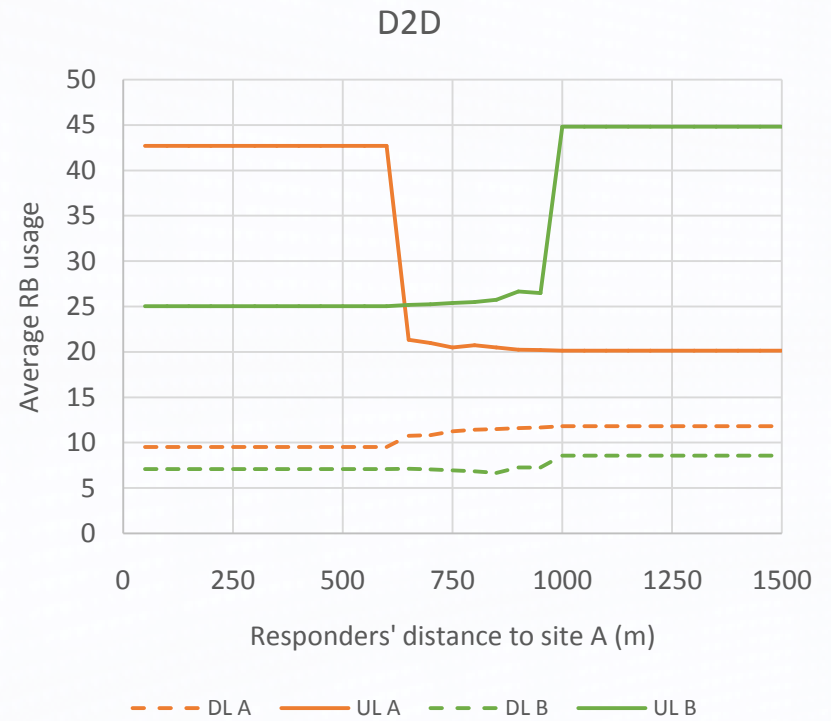
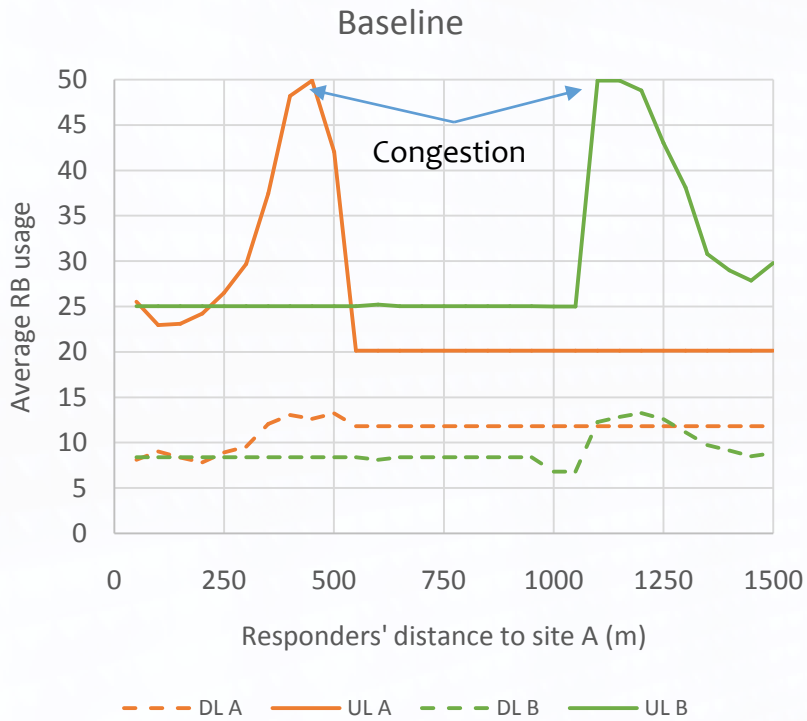
Baseline vs D2D



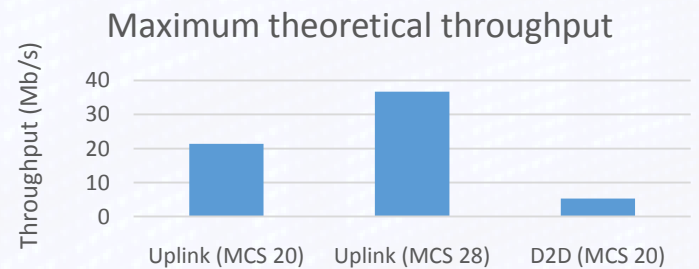
- When in coverage, the resources needed by the responders depend on their relative location to each other
- MCS 20 was used for both in coverage and out of coverage case

Resource Block Usage

Baseline vs D2D

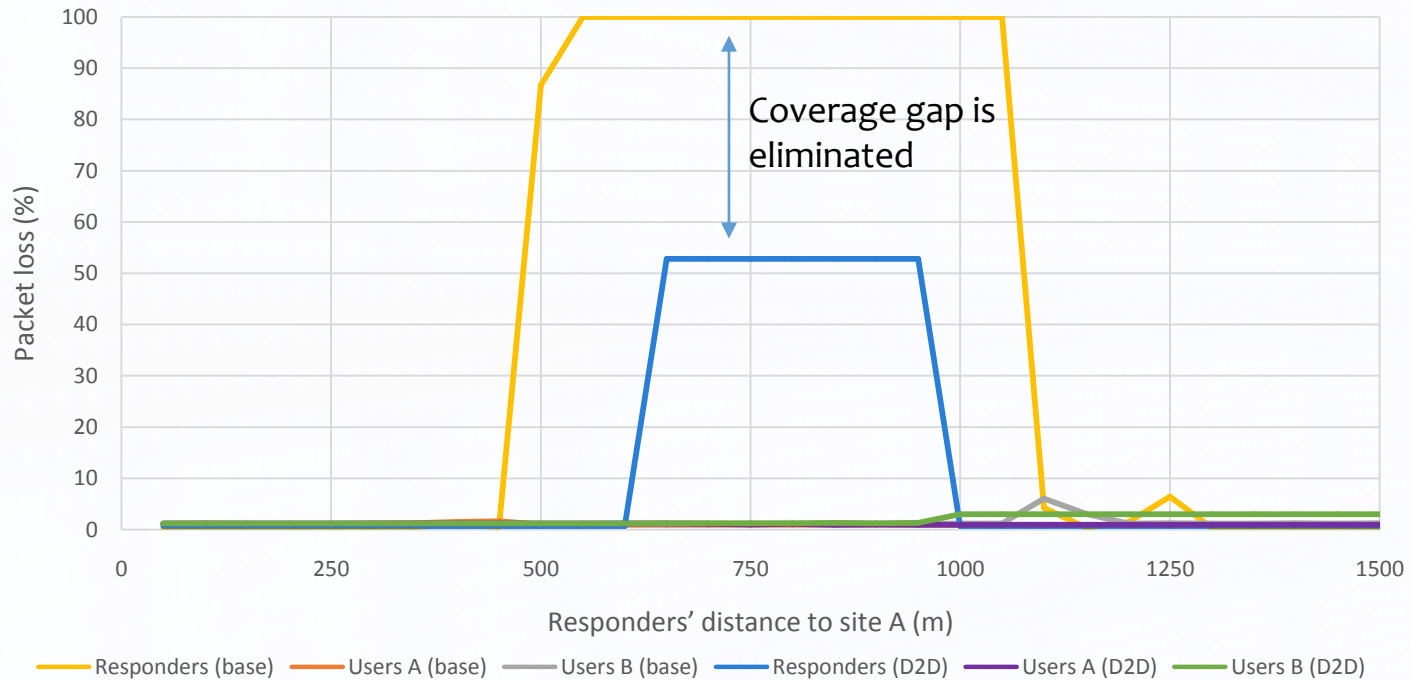


- D2D protocol (pool, MCS, retransmissions) may not be as efficient as uplink transmissions and results in higher RB usage



Packet loss

Baseline vs D2D



- When the responders are out of coverage, we observe that packets are still being exchanged
- The lack of synchronization between users results in collision so only a portion of the traffic goes through

3GPP: Work Items for Release 13

- ▣ Discovery
 - ▣ Type 1 discovery (i.e. resources allocated on non-UE specific basis) for partial and outside network coverage (PS only)
 - ▣ Restricted Discovery
 - ▣ Support for multiple carriers and Public Land-Mobile Networks (PLMNs)
- ▣ Communication
 - ▣ Coverage extension using UE-to-Network Relays
 - ▣ Group priority
 - ▣ Support for Mission Critical Push-To-Talk (MCPTT)
 - ▣ Service continuity
- ▣ Items applying to both Discovery and Communication
 - ▣ In network coverage enhancements
 - ▣ Co-existence interference with adjacent carrier frequencies
 - ▣ Impact on cellular traffic and its QoS

Resiliency Strategy Summary

Strategy	Pros	Cons/Limitations
Traffic Control	<ul style="list-style-type: none">• Can increase coverage for both uplink and downlink	<ul style="list-style-type: none">• Does not increase reference coverage
High Power UE	<ul style="list-style-type: none">• Increase uplink coverage	<ul style="list-style-type: none">• Interference• Does not increase reference coverage
Parameter Configuration	<ul style="list-style-type: none">• Can increase coverage and capacity	<ul style="list-style-type: none">• Complex
D2D Communication	<ul style="list-style-type: none">• Provides out of network coverage	<ul style="list-style-type: none">• Limited throughput• No reliability

- The performance evaluation results show that there is no “silver bullet” to maintain connectivity during site outages
- A combination of multiple solutions is needed to provide the coverage and capacity needed for Public Safety

Current Activities

- ▣ Understanding additional resiliency strategies
- ▣ Investigating different outage & incident traffic distributions
- ▣ Developing guidelines and insights for using resiliency strategies in response to outages:
 - ▣ Our results so far indicate that the benefits of the various resiliency strategies depend on the outage and network deployment
 - ▣ In order to be effective solutions need to be accessible to Public Safety and deployed/activated quickly when outages occur
 - ▣ Which solution to apply in real time when an outage occurs?

Thank you!

Questions?

Backup

Impact of Outage on Modeling Assumptions

Topology

eNodeB distance (m)	1600
Users A distance to eNodeB (m)	[225,250]
Users B distance to eNodeB (m)	[275,250]

eNodeB

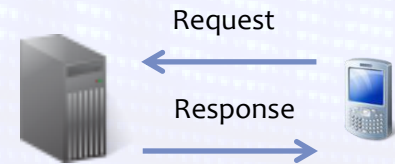
Antenna model	3GPP TR 36.814 (Macro-cell)
Mechanical tilt (degree)	10
Propagation model	Cost 231
Shadowing (dBm)	10
Bandwidth DL+UL (MHz)	10 + 10
Tx Power (dBm)	46
Scheduler	Round Robin

UE

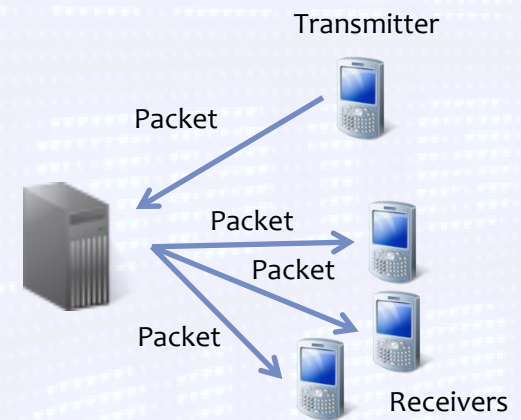
Antenna model	Omnidirectional
Antenna gain (dB)	0
Tx Power (W)	0.2, 1.2
RSRP threshold (dBm)	-110

Traffic

Number of users per cell	10		
User traffic distribution	Constant bitrate (CBR)		
User packet size (byte)	1280		
User packet interval (s)	0.02	Data rate (kb/s)	512
Number of responders	10		
Responder traffic distribution	CBR		
Responder packet size (byte)	256		
Responder packet interval	0.02	Data rate (kb/s)	102.4



User traffic model



Group communication traffic model