Evaluating Multicast Capability in LTE Public Safety Networks

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#PSCR2019

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Outline

Motivation

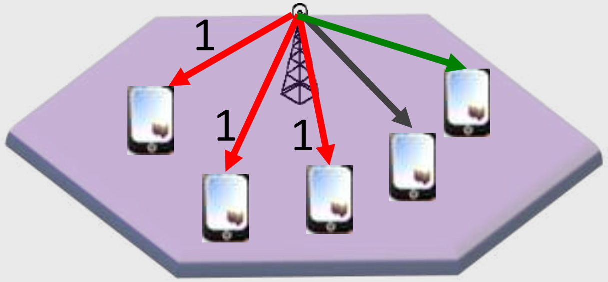
Multicast vs unicast evaluation

Conclusion and next steps

What Multicast Is

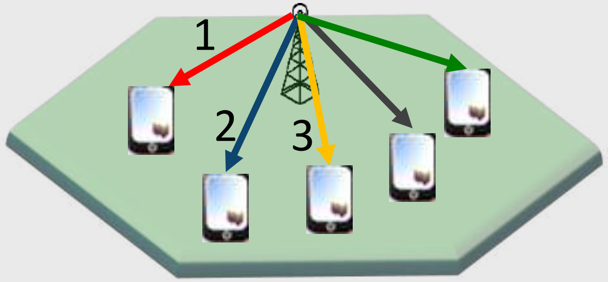
Multicast

Send the same copy of content to multiple users



Unicast

Send multiple copies of the same content to multiple users



Multicast could potentially save spectrum significantly.

Characteristics that Differentiate Public Safety

Significant amount of multicast traffic

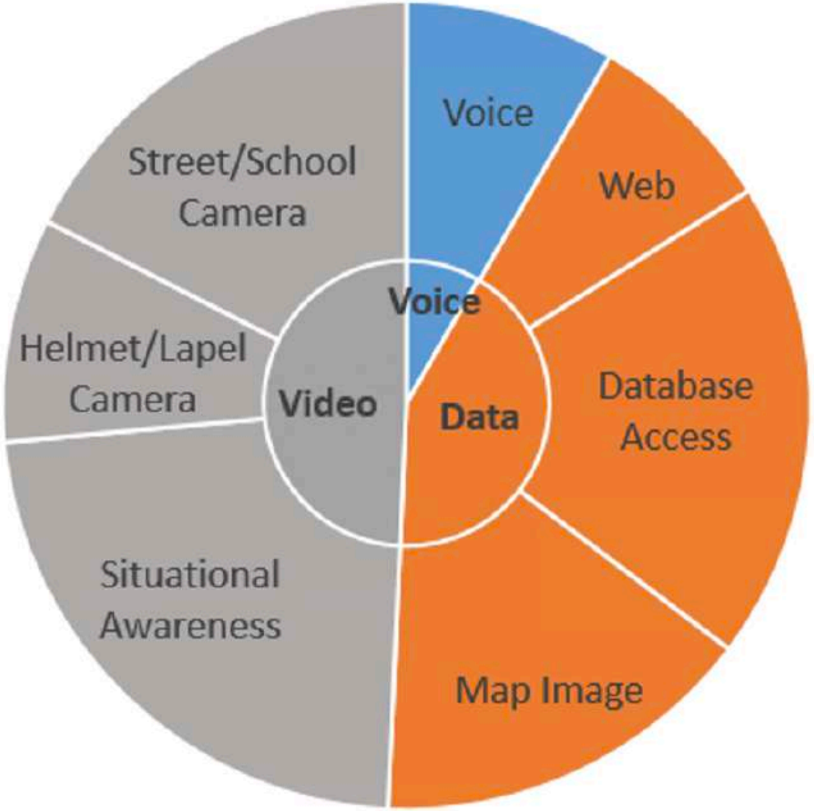
Ex. public safety traffic in a school shooting incident reported by

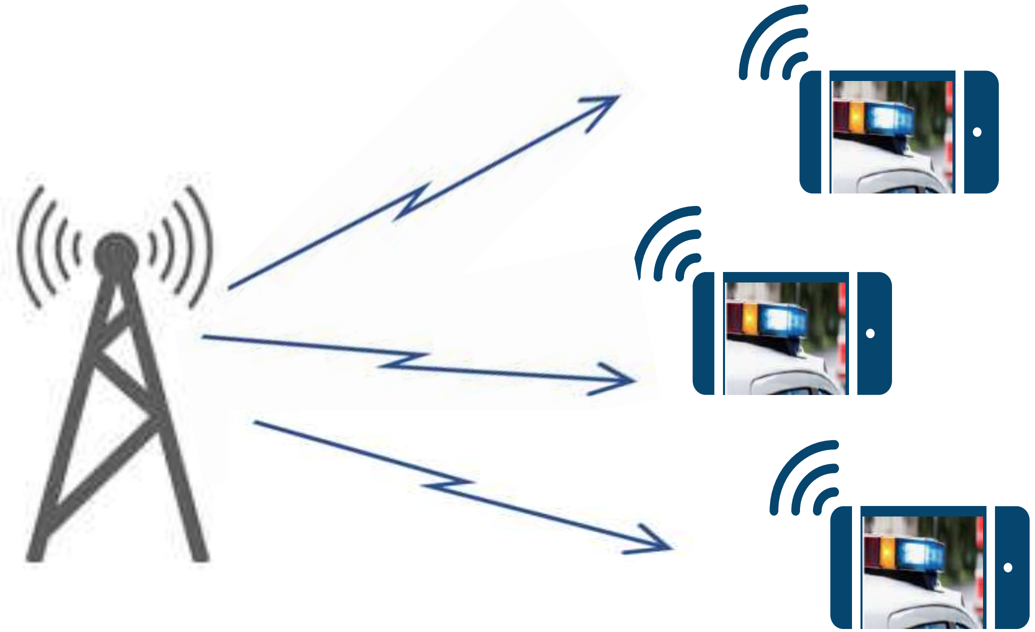
Future Metro Scenario	Peak Uplink kb/s	Peak Downlink kb/s	Average Uplink kb/s	Average Downlink kb/s
w/ multicast	5263	11366	4298	7596
w/o multicast	5691	17148	4817	12861

>50 % reduction in average downlink traffic demand w/ multicast

Characteristics that Differentiate Public Safety

Variety of public safety applications



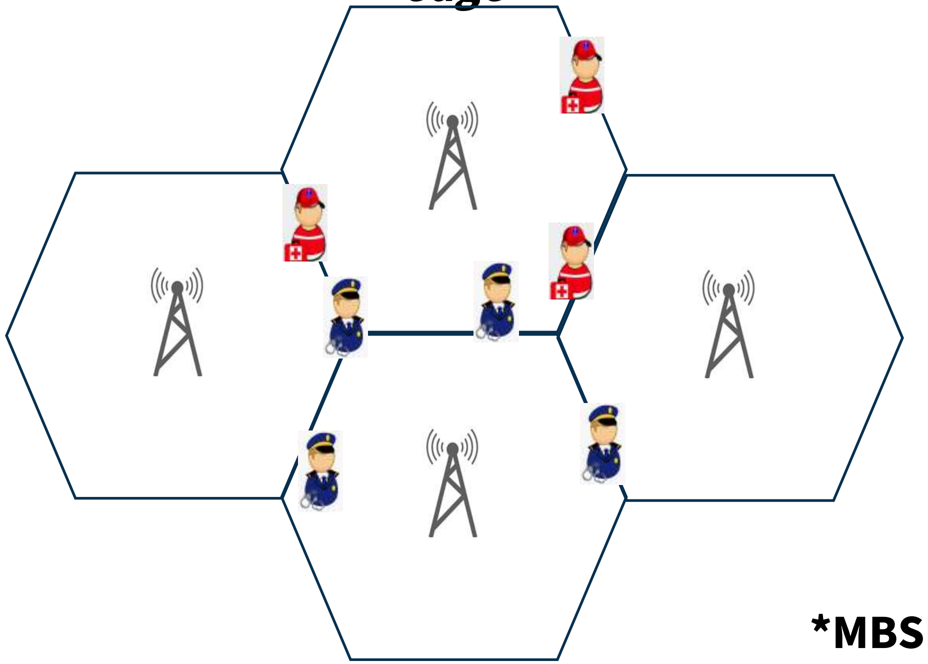


Applications with high throughput requirement such as mission critical video

Characteristics that Differentiate Public Safety

Stringent coverage requirement

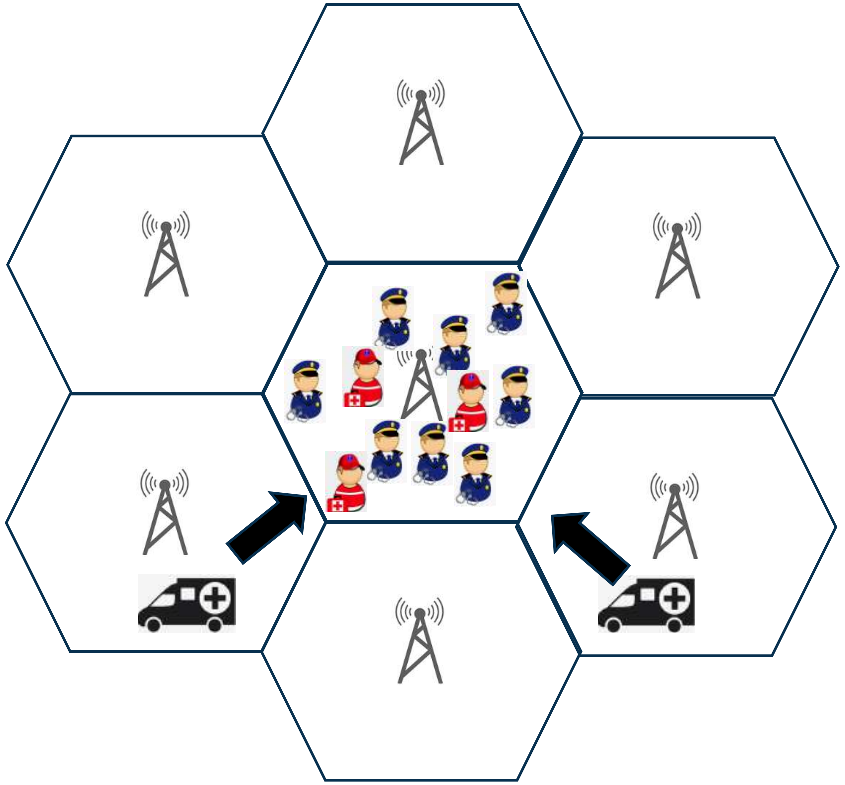
Multicast approach MBSFN* is designed to enhance user signals especially at cell edge



***MBSFN: Multimedia Broadcast Multicast Service Single Frequency Network.**

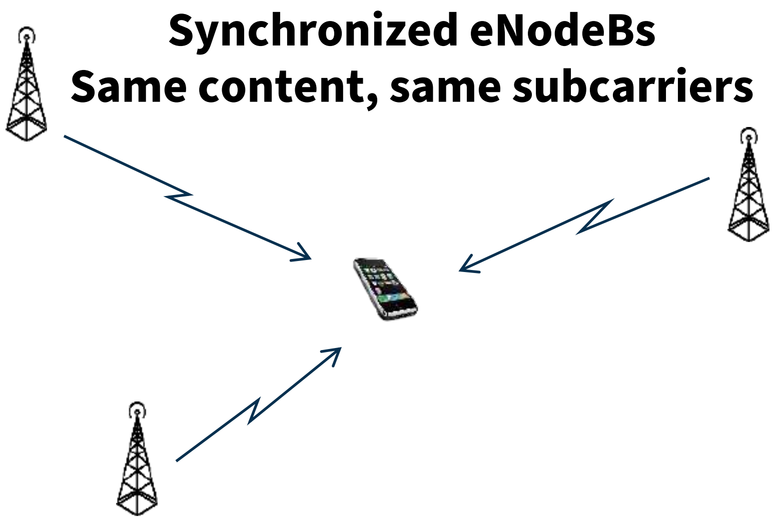
Characteristics that Differentiate Public Safety

Concentrated incident area



Leverage commercial technologies to meet public safety needs.

A Bit More About MBSFN ….

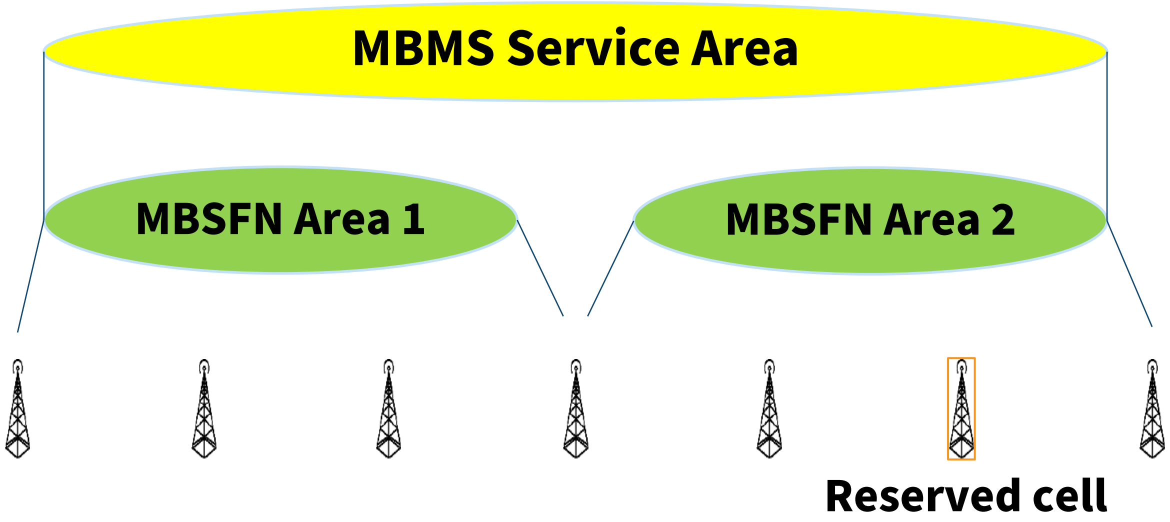


MBSFN transmissions

- Multiple cells transmit identical waveforms at the same time.
- A device treats transmissions in the same way as multipath components of a single cell transmission.
- MBSFN benefits from multi-cell combining (MBSFN gain) as well as reduction of interference from neighbor cells.

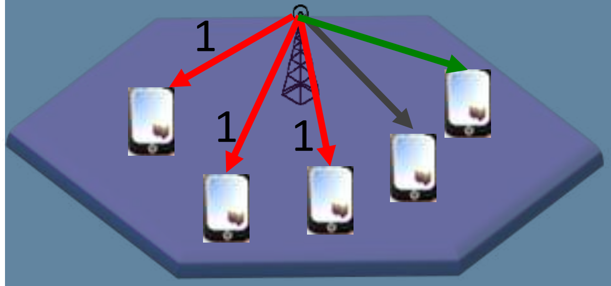
Semi-static MBSFN area

- Except for the Reserved Cells, all cells within an MBSFN Area contribute to the MBSFN Transmission.



MBMS: Multimedia Broadcast Multicast Services.

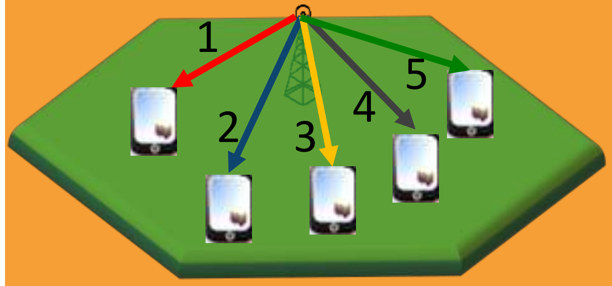
MBSFN vs Unicast



MBSFN

Pros:
- MBSFN gain.
- One copy to be sent regardless of # FRs*.

Cons:
- No spatial multiplexing, no transmit diversity.
- 60 % resources available.
- Transmission rate limited by the worst SINR* experienced by all FRs.
- Semi-static MBSFN area, less adaptive to FR location distributions.



Unicast

Pros:
- Spatial multiplexing & transmit diversity.
- 100 % resources available.

Cons:
- SINR penalty at cell edge or shadowing.
- Multiple copies to be sent, increasing linearly with # FRs.

* # FRs: number of First Responders.
SINR: Signal-to-interference-plus-noise Ratio.

Evaluation Methodology

02

Little information

FRs available

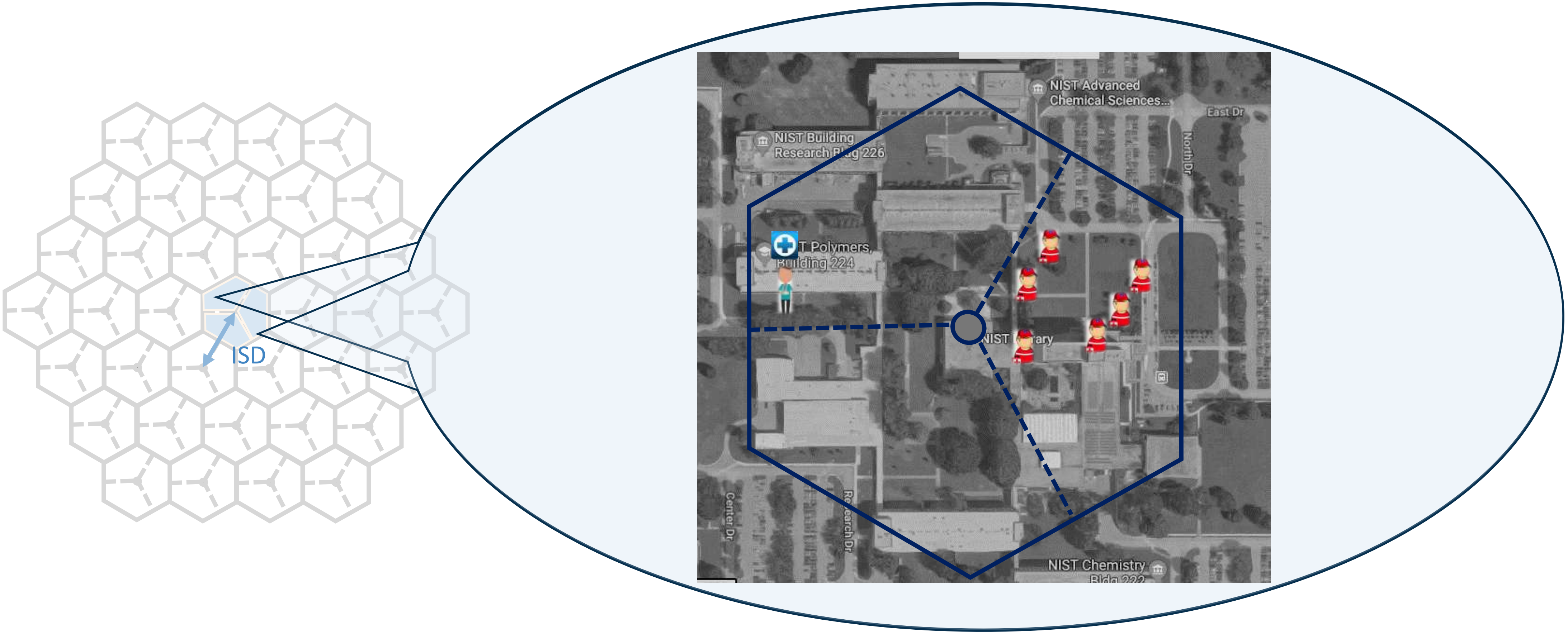
Real-time SINR available

01

03

- **MBSFN vs unicast performance was evaluated based on -**
  - **Available information on public safety incidents.**
  - **Variety of first responders’ performance requirements.**
- **MBSFN mathematical models were derived.**
- **High fidelity MBSFN link level and system level simulation platform was implemented.**

Network Under Study



Baseline: 8x4, Inter-Site-Distance(ISD) 500 m, urban macroscopic pathloss, VehB 120 km/h small scale fading , evenly distributed FRs.

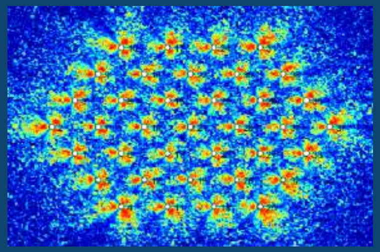
Evaluation Framework

Input Parameters

Static
- eNodeB ISD.
- Channel Model.
- MIMO* Configuration.

Dynamic
- FR distribution.
- Number of FRs.

Comprehensive LTE Network Simulator (PHY,MAC)



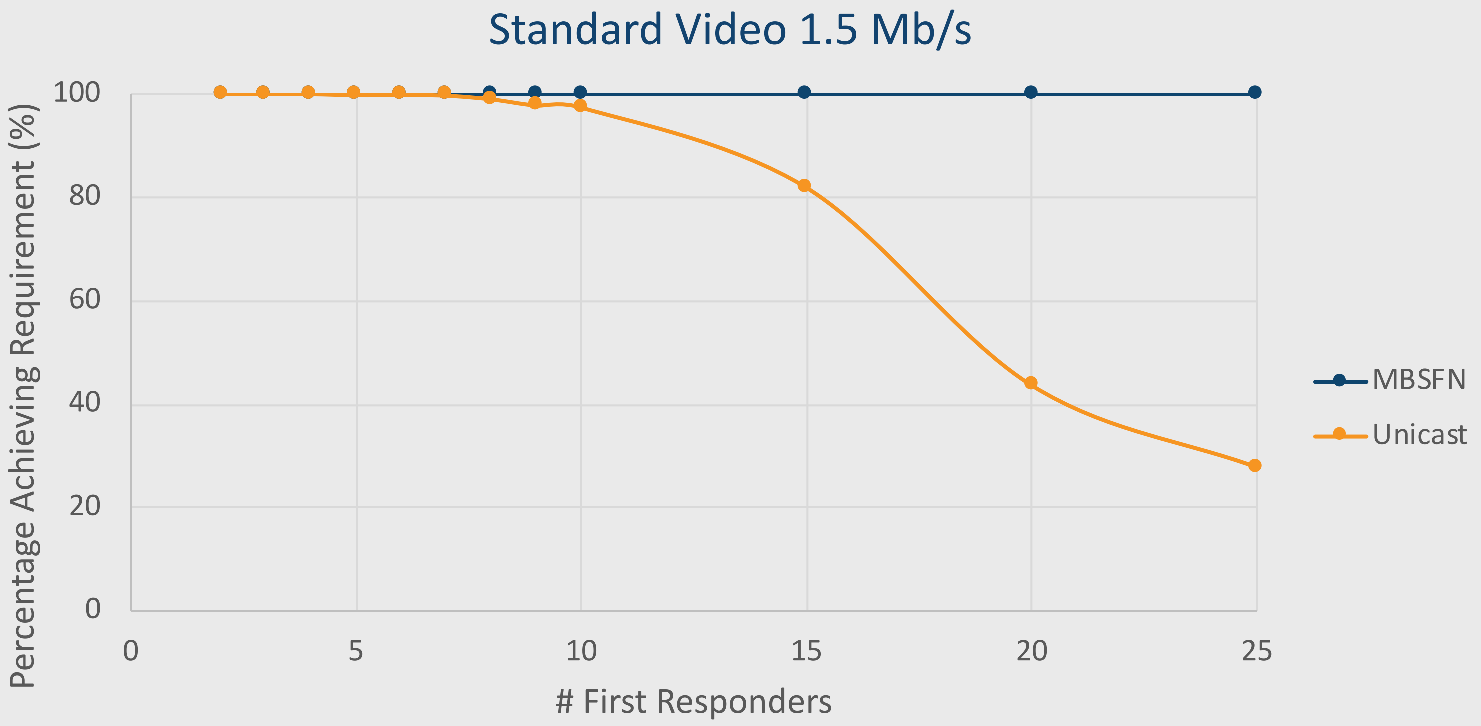
Output Results
- Coverage.
- Throughput.
- Flight Time.
- Utilized resource.

* **MIMO: M**ultiple-Input and Multiple-Output

Different metrics are selected to fit requirements from variety of FR applications and traffic mix.
- **Coverage: percentage of FRs that meet minimum throughput requirement.**
- **Throughput: full buffer traffic.**
- **Flight time: 0.1 Mbytes file transfer.**
- **Utilized resource: the amount of resource utilized to achieve the performance.**

Coverage

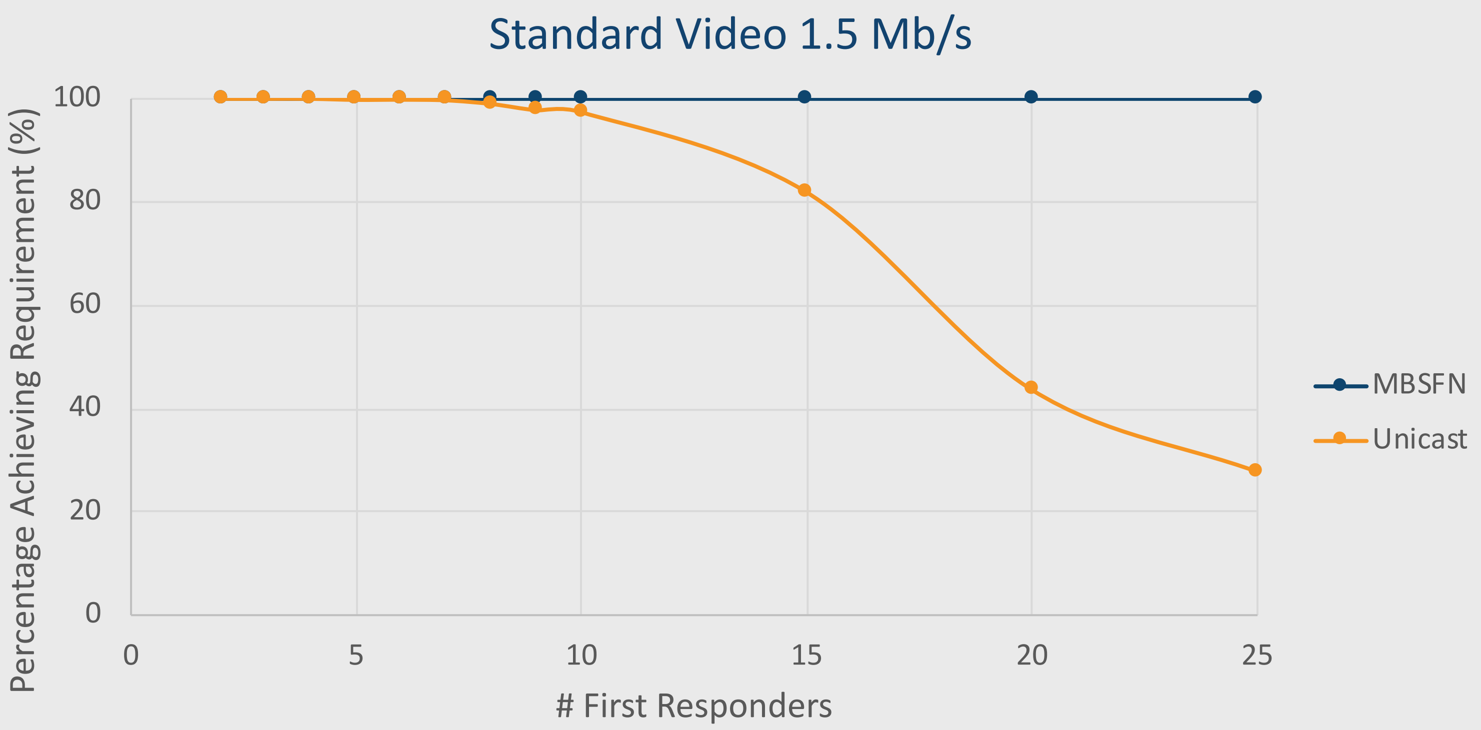
Percentage of FRs who could achieve throughput requirement



- **For MBSFN, the percentage does not change significantly with # FRs.**
- **For unicast, after a certain # FRs, the percentage decreases significantly with increasing # FRs.**

Coverage

Percentage of FRs who could achieve throughput requirement



	1.5 Mb/s Standard video
MBSFN	~ 100 %
Unicast	

- **For MBSFN, the percentage does not change significantly with # FRs.**
- **For unicast, after a certain # FRs, the percentage decreases significantly with increasing # FRs.**

MBSFN leaves 40 % resource available for other traffic.

Results

- **MBSFN meets minimum throughput requirements.**

02

Little information

FRs available

Real-time SINR available

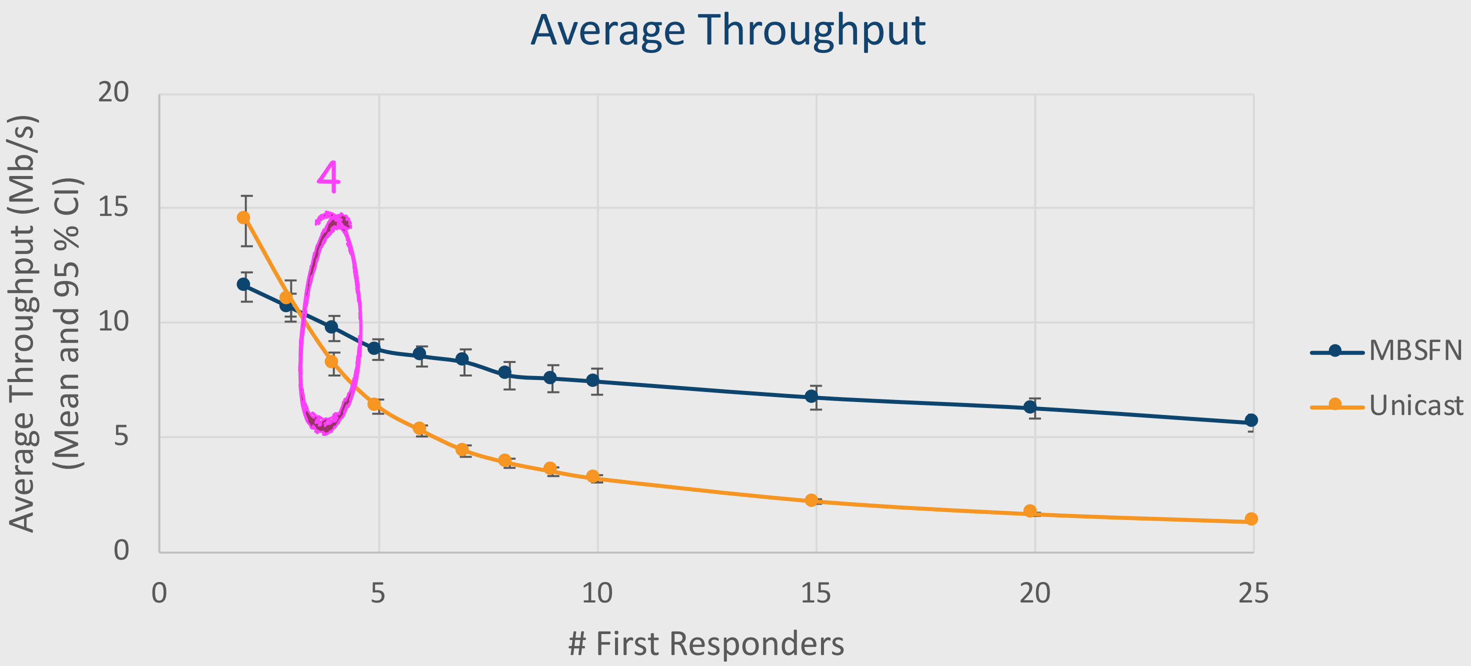
01

03

MBSFN leaves 40 % resource available for other traffic.

Throughput

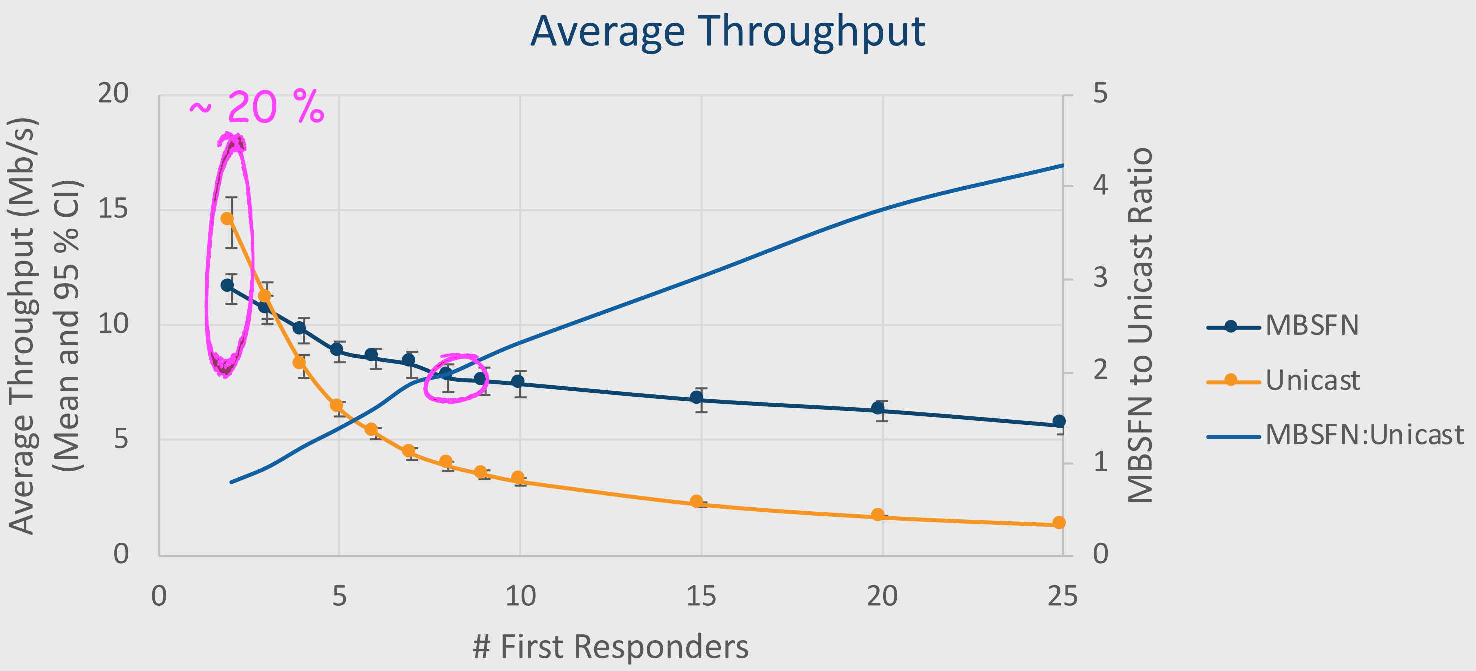
Performance trends and switch point



- **MBSFN and unicast throughputs follow different trends with increasing # FRs.**
  - **FR throughput in unicast decreases much faster than that in MBSFN.**
- **There exists a switch point in terms of # FRs.**
  - **Unicast outperforms below the switch point, and MBSFN outperforms otherwise.**

Throughput

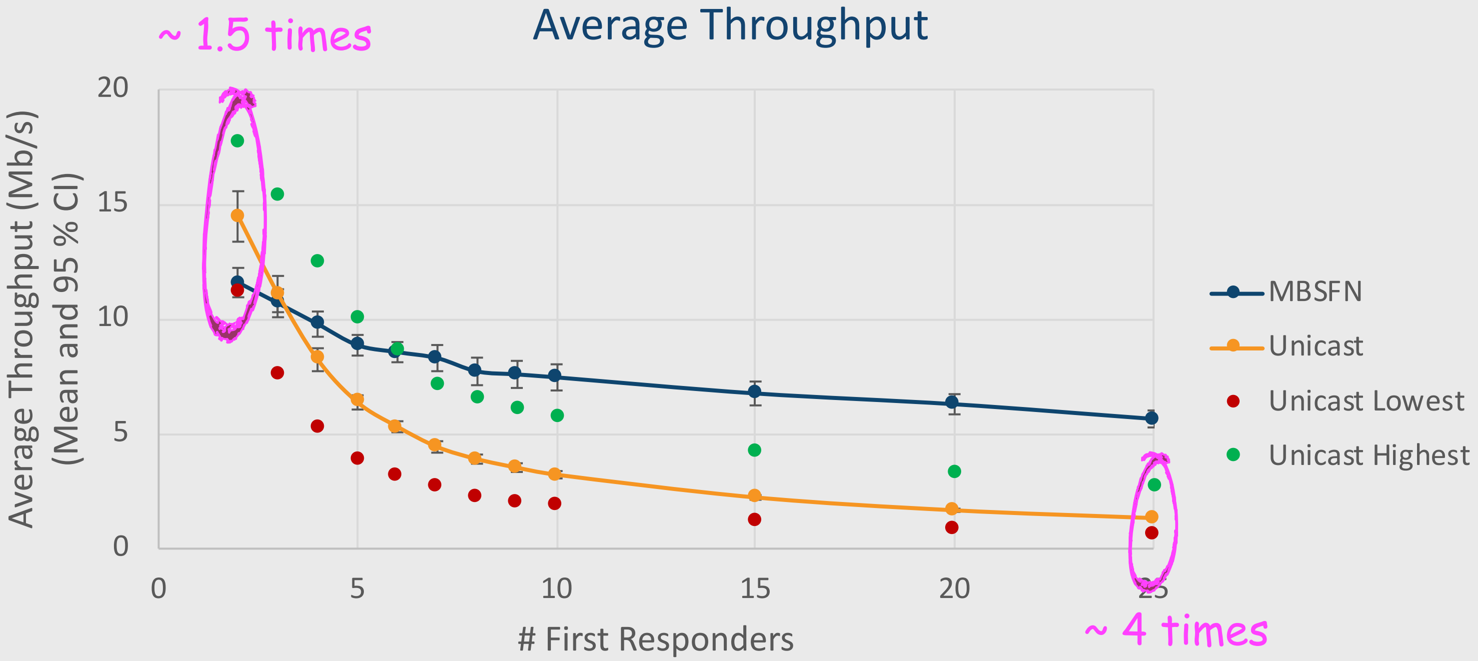
Performance delta and penalty



- **Throughput delta between MBSFN and unicast increases quickly with # FRs.**
  - **When there are eight FRs, MBSFN throughput is around twice as much as unicast throughput.**
- **If no switch point is considered and MBSFN is always selected, the highest penalty in average throughput is ~ 20 %, statistically.**
  - **There is no bound on penalty in percentage if unicast is always selected.**

Throughput

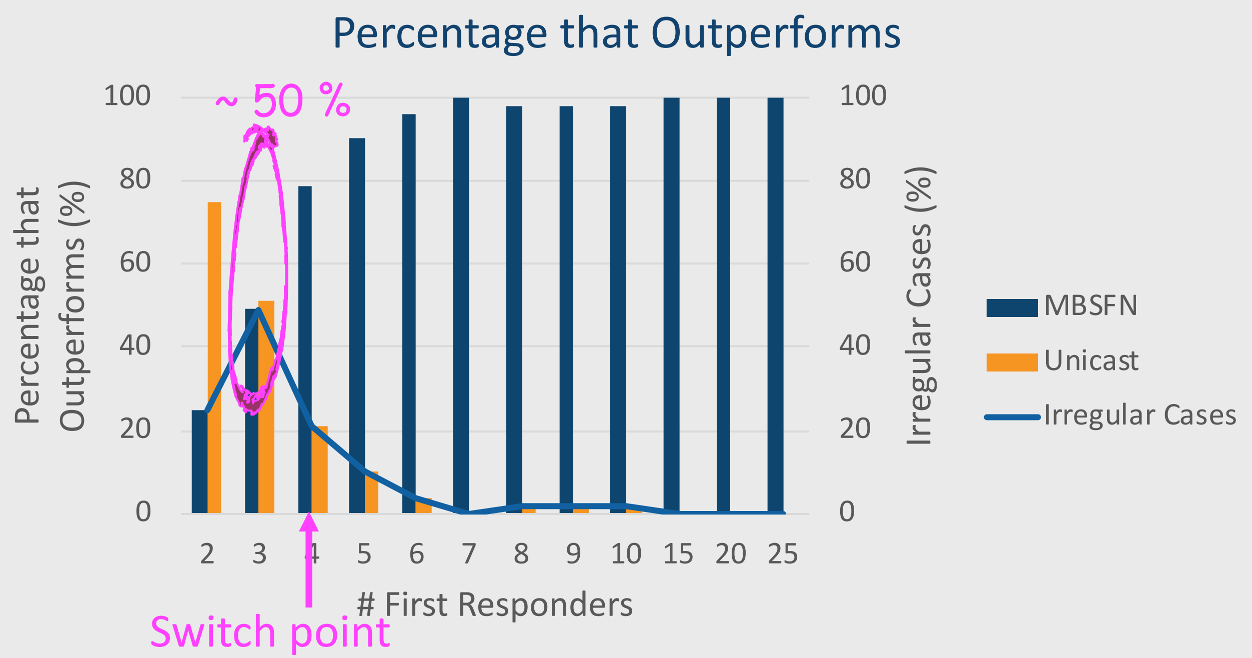
Performance spread



- **In unicast, FRs may experience different throughputs.**
  - **The throughput spread could be significant.**
- **In MBSFN, every FR experiences the same throughput.**

Throughput

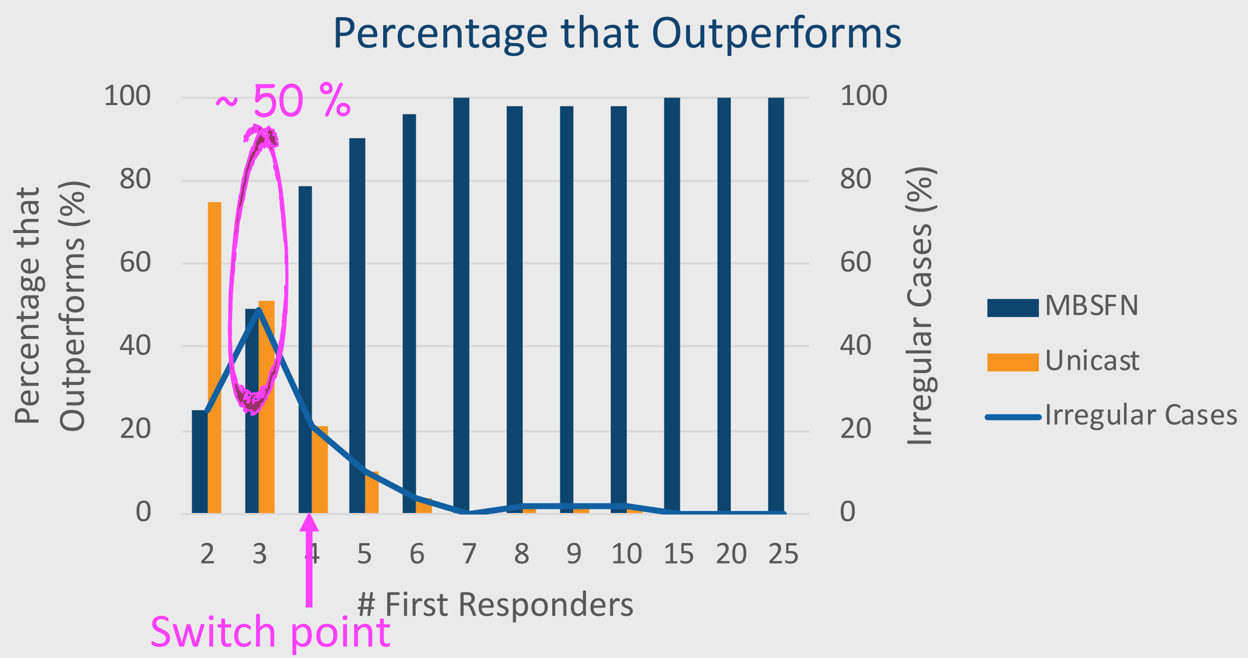
Cost of irregular cases

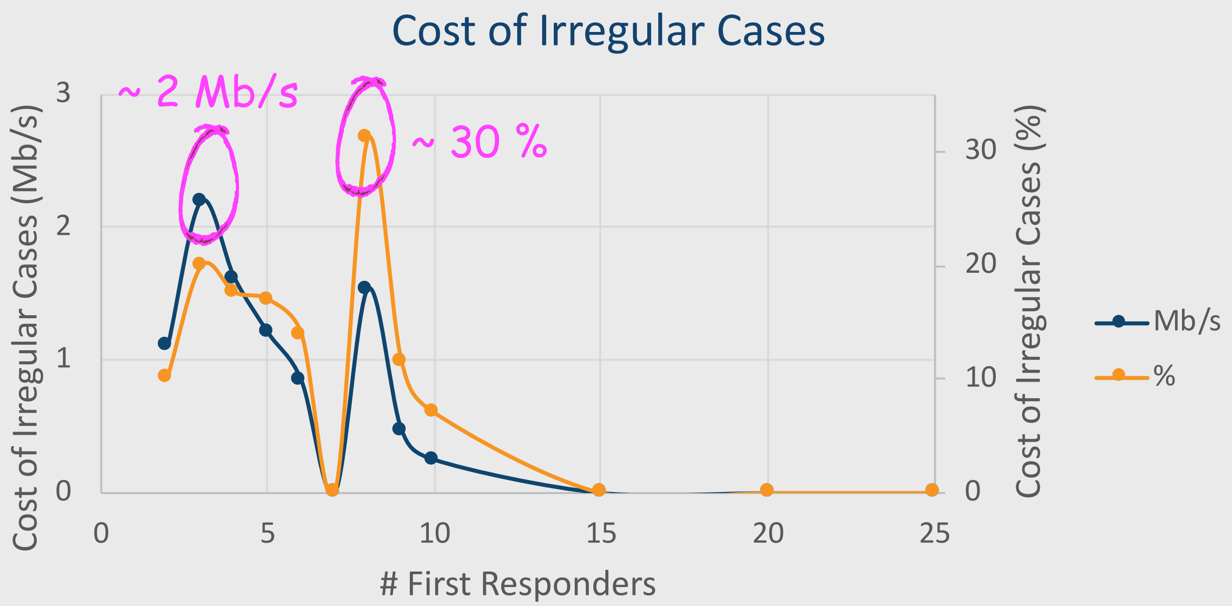


- **There exist irregular cases that do not follow the switch point.**
  - **Their percentage could be as high as ~50 %.**
  - **The percentage decreases to close to zero when # FRs is high.**
- **The highest penalty for irregular cases is ~ 2.2 Mb/s, or ~ 30 % less average throughput.**

Throughput

Cost of irregular cases





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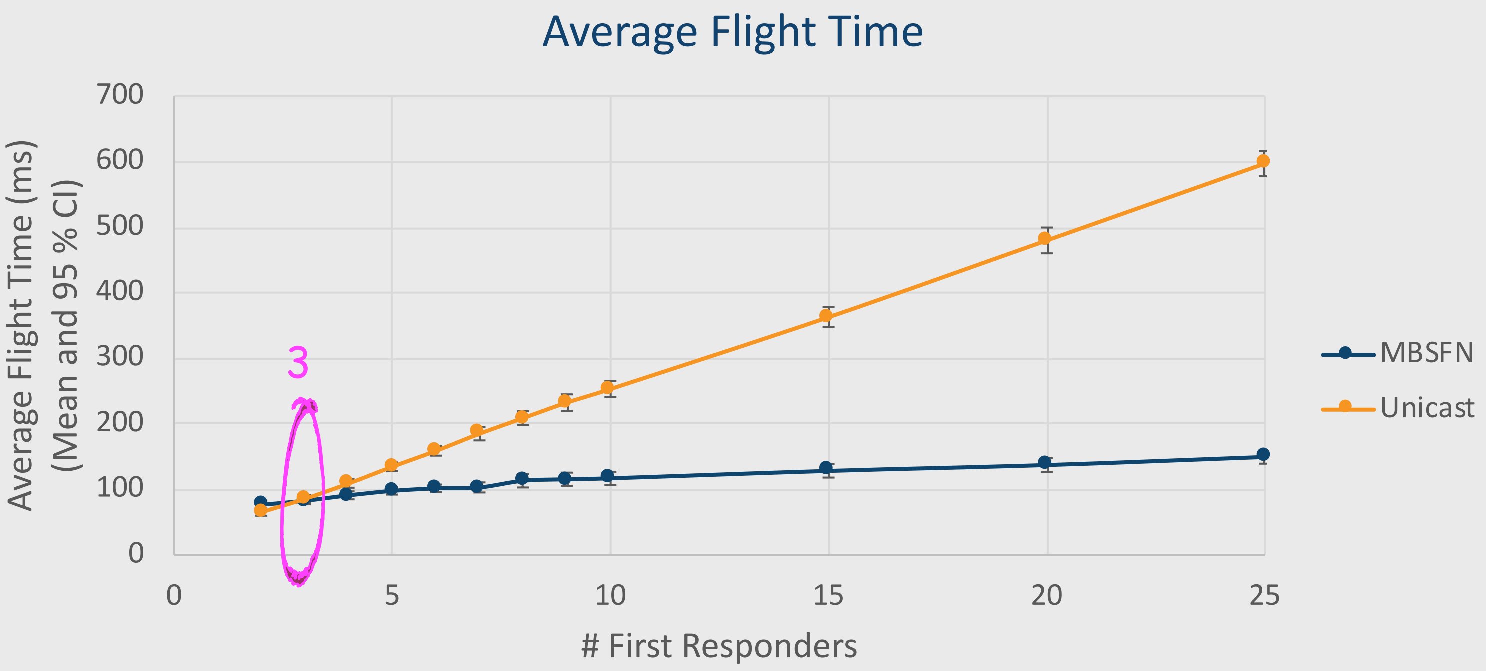
MBSFN leaves 40 % resource available for other traffic.

Flight Time

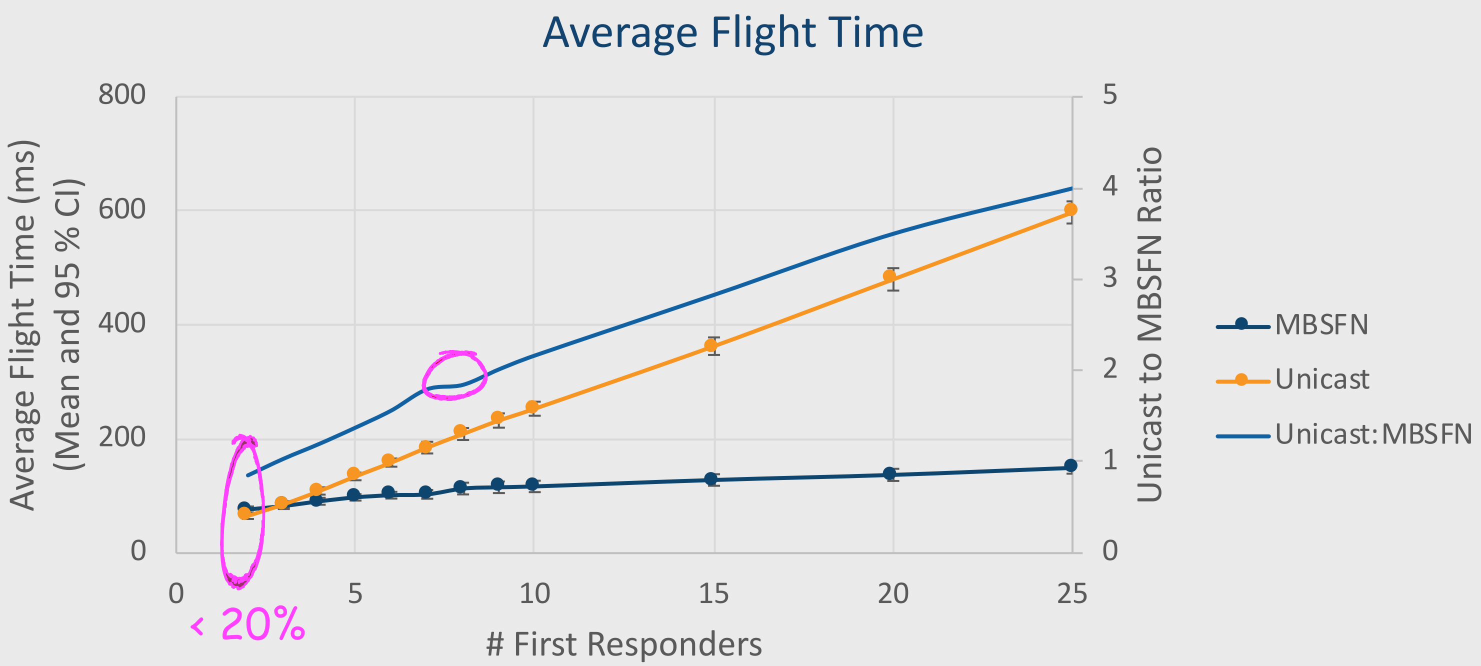
Performance trends and switch point



- **MBSFN and unicast flight times follow different trends with increasing # FRs.**
  - **In unicast and with increasing # FRs, the average time for FRs to receive the content increase significantly.**
- **There exists a switch point. The switch point is different from throughput switch point.**

Flight Time

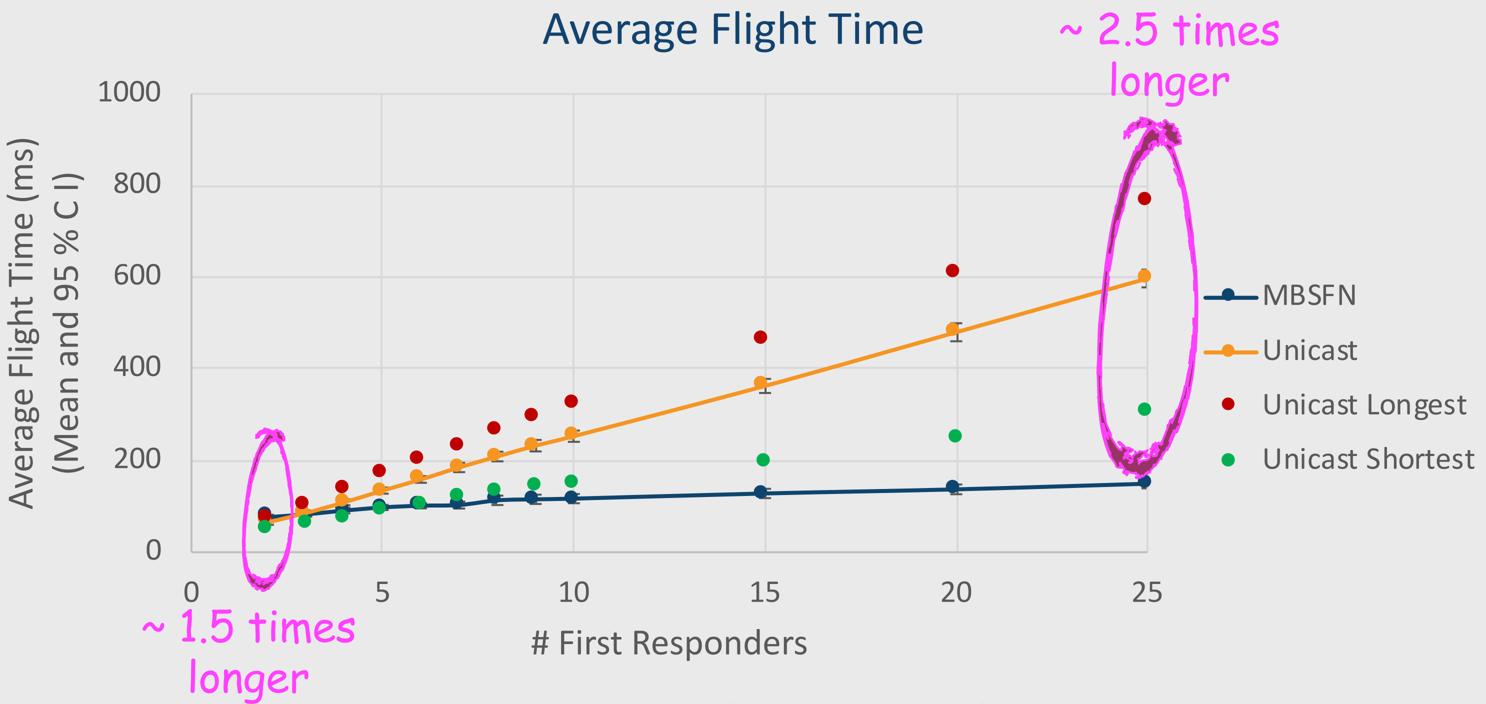
Performance delta and penalty



- **Performance delta between MBSFN and unicast increases with # FRs.**
  - **When there are eight FRs, unicast would take about twice as long as MBSFN for the FRs to receive the content, on average.**
- **If no switch point is considered and MBSFN is always selected, the highest penalty in average throughput is < 20 %, statistically.**
  - **There is no bound on penalty in percentage if unicast is always selected.**

Flight Time

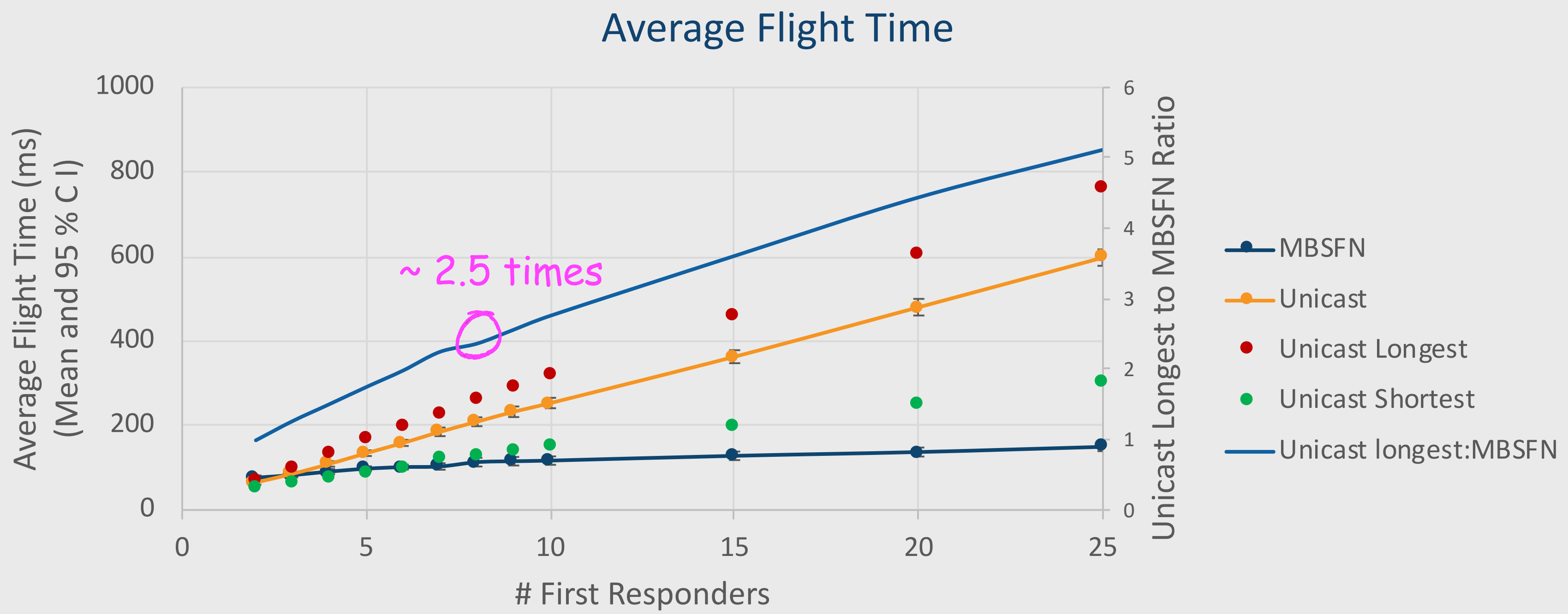
Performance spread



- **In unicast, FRs may experience different duration to receive the same content.**
  - **The duration spread could be significant.**
- **In MBSFN, every FR experiences the same duration.**

Flight Time

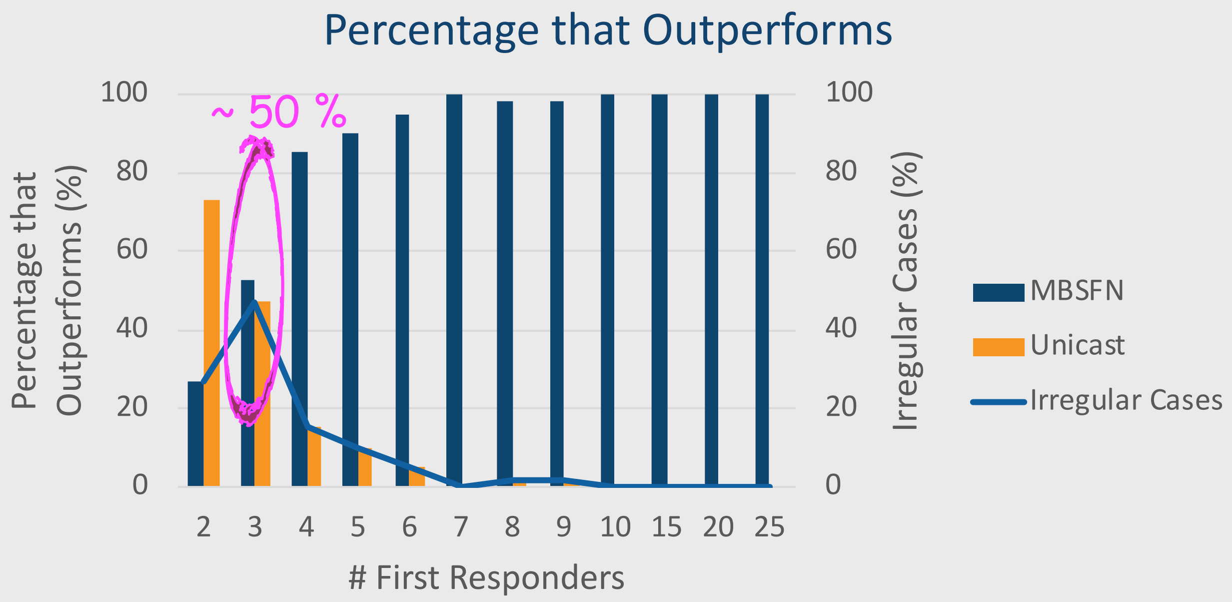
Performance covering every FR

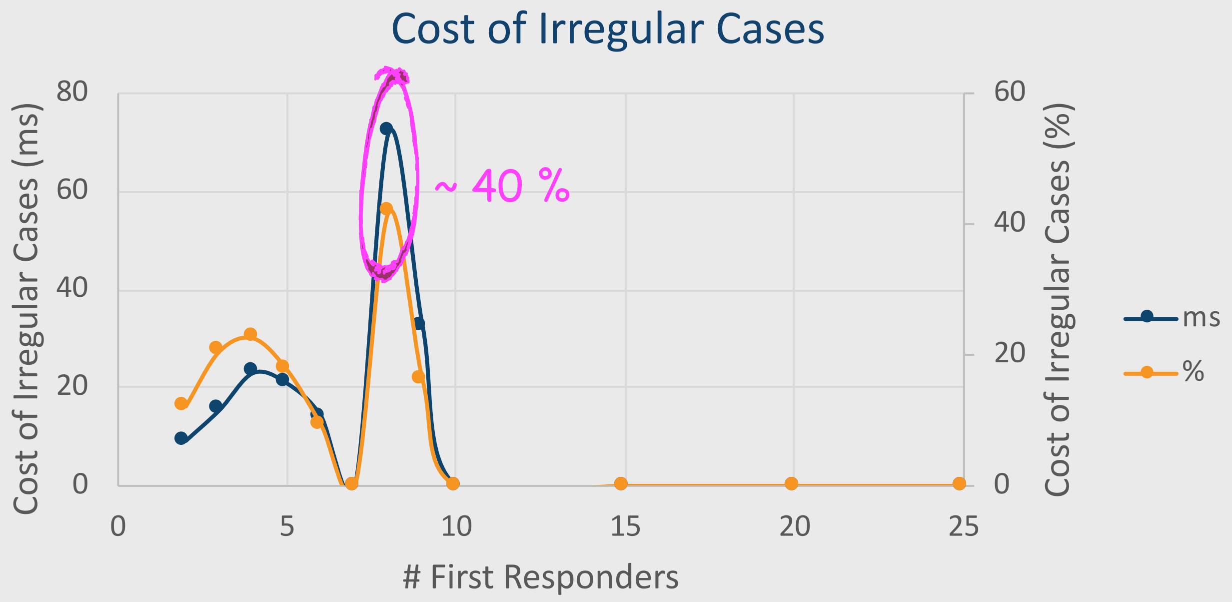


- **For every FR to receive the content, the ratio between the durations in unicast and MBSFN increases significantly with # FRs.**
  - **When there are eight FRs, unicast takes ~ 2.5 times as long as MBSFN does.**

Flight Time

Cost of irregular cases





- **There exist irregular cases that do not follow the switch point.**
  - **Their percentage could be as high as ~50 %.**
  - **The percentage decreases to close to zero when # FRs is high.**
- **The highest penalty for irregular cases is ~ 40 % longer time for FRs to receive the content.**

MBSFN leaves 40 % resource available for other traffic.

Results

- MBSFN meets minimum throughput requirements.
- MBSFN outperforms significantly in majority cases, with < 20 % penalty in other cases, statistically.

02

Little information

FRs available

Real-time SINR available

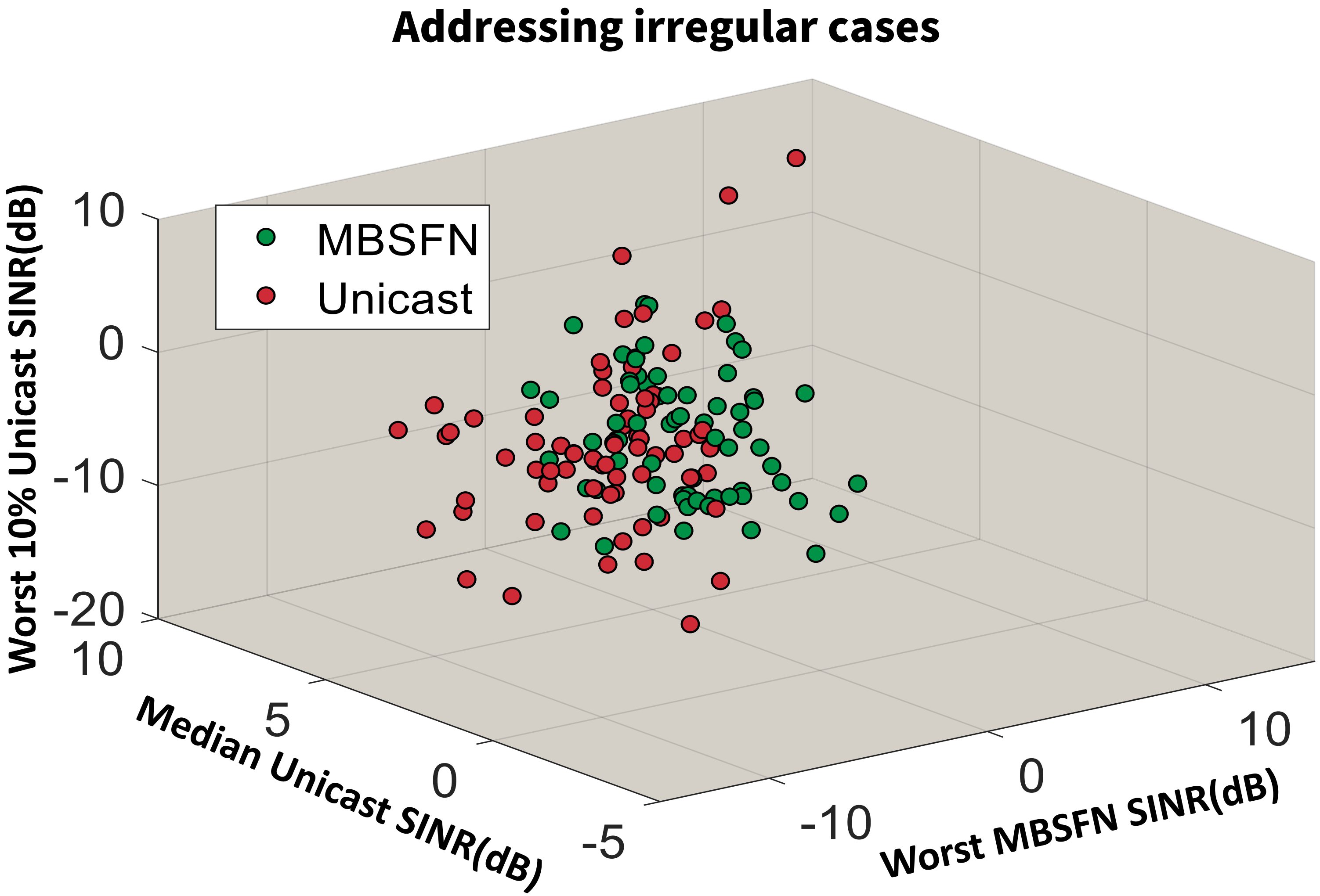
01

- Switch point could be used to make selection.
- Different metrics lead to different switch points.
- Performance delta increases with # FRs.
- FR experience spread exists in unicast.
- Percentage of irregular cases could be as high as ~ 50 %.
- The highest penalty for irregular cases is ~ 30 % less average throughput, or ~ 40 % longer duration, statistically.

03

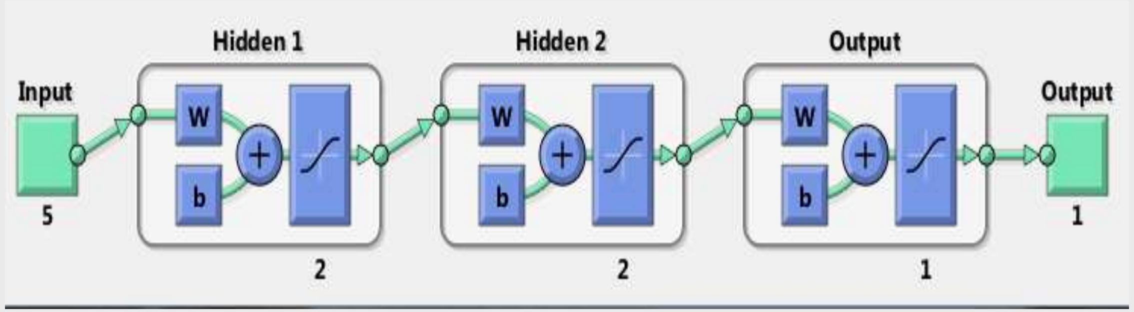
MBSFN leaves 40 % resource available for other traffic.

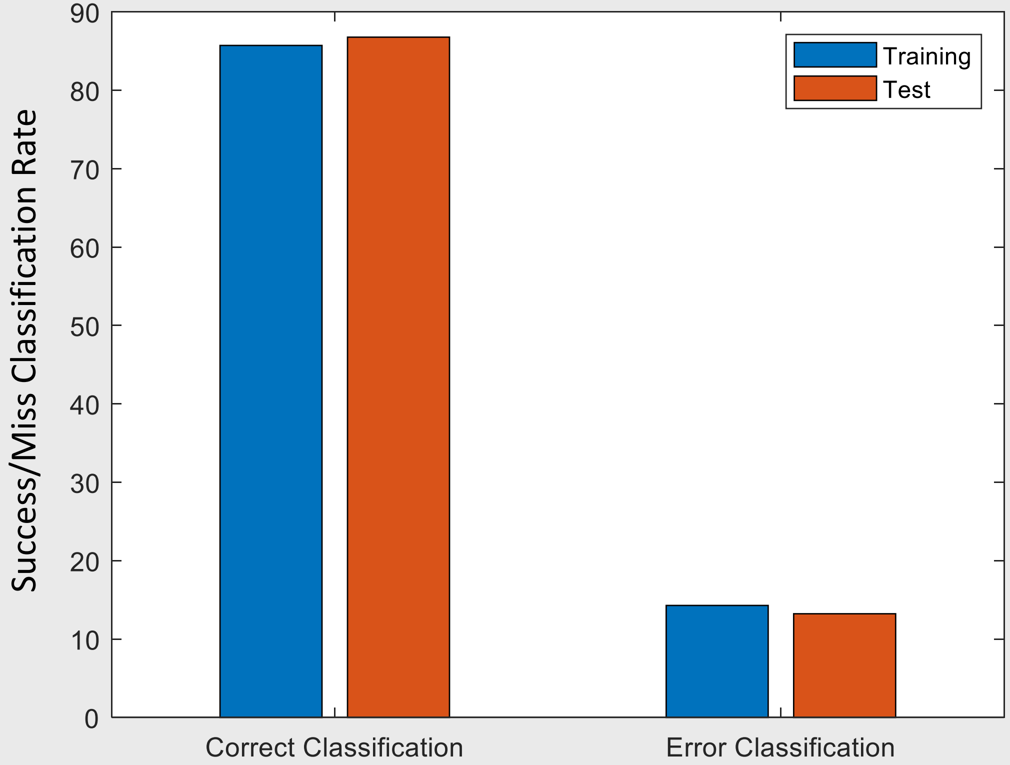
SINR Based Pattern Searching



Winning cases seem to be separable, but no clear pattern.

Machine Learning





Machine learning is being investigated and three signatures were selected –

- **Worst MBSFN SINR.**
- **Worst 10 % unicast SINR.**
- **Median unicast SINR.**

Percentage of irregular cases is reduced from ~ 50 % to ~ 15 %.

- **~ 85 % success classification rate is achieved.**

Results

- MBSFN meets minimum throughput requirements.
- MBSFN outperforms significantly in majority cases, with < 20 % penalty in other cases, statistically.

02

- Real time decision based on SINR and machine learning algorithm reduces percentage of irregular cases significantly.

Little information

FRs available

Real-time SINR available

01

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03

MBSFN leaves 40 % resource available for other traffic.

Performance with MIMO Configurations

- Public safety incidents could occur at a variety of locations, with variety of network deployments.
- First responders could use a variety of devices with different capabilities.
- Investigation on different MIMO configurations showed similar performance behavior, with different switch points.

Switch points under different MIMO configurations

MIMO Configuration	2x1	2x2	4x1	4x2	4x4	8x1	8x2	8x4	8x8
Throughput switch point, # FRs	M	3	M	M	M	6	3	4	5
Flight time switch point, # FRs	M	4	M	M	M	U	4	3	4

U: unicast is always better up to current data points.
M: MBSFN is always better up to current data points.

Performance for Various Network Environments

- **3GPP* and ITU* channel models were applied to simulate a variety of network environments public safety incidents may incur.**
- **Evaluation results show similar behavior, with slightly different switch points.**

Switch points under small scale fadings

Fast fading model	PedB 10 km/h	VehA 30 km/h	VehB 120 km/h
Throughput switch point, # FRs	5	5	5

Small scale fading model: ITU PedB 10 km/h, VehA 30 km/h, or VehB 120 km/h.

Switch points under macroscopic pathlosses and ISDs

Path loss and ISD	Urban 500 m	Urban 1299 m	Rural 1299 m	Rural 1732 m
Throughput switch point, # FRs	5	6	4	4

Macroscopic pathloss model: 3GPP TS36.942 urban and rural.

*** 3GPP: The 3rd Generation Partnership Project.**
ITU: The International Telecommunication Union.

Results

01

Little information

- MBSFN meets minimum throughput requirements.
- MBSFN outperforms significantly in majority cases, with < 20 % penalty in other cases, statistically.

02

 # FRs available

- Switch point could be used to make selection.
- Different metrics, MIMO configurations, and network environments may lead to different switch points.
- Performance delta increases with # FRs.
- FR experience spread exists in unicast.
- Percentage of irregular cases could be as high as ~ 50 %.
- The highest penalty for irregular cases is ~ 30 % less average throughput, or ~ 40 % longer duration,

MBSFN leaves 40 % resource available for other traffic.

03

Real-time SINR available

- Real time decision based on SINR and machine learning algorithm reduces percentage of irregular cases significantly.

Evaluation Takeaways

01 — Little information

- MBSFN meets minimum throughput requirements.
- MBSFN outperforms significantly in majority cases.

02 — # FRs available

- Switch point could be used to make selection.
- Performance delta increases with # FRs.
- FR experience spread exists in unicast.

03 — Real-time SINR available

- Real time decision could be based on SINR and machine learning algorithm.

MBSFN leaves 40 % resource available for other traffic.

Conclusion and Next Steps

MBSFN mathematical model was derived, and high fidelity and flexible simulation platform was implemented into commercial software.

MBSFN and unicast are evaluated under multiple performance metrics and network deployments, from performance perspective only.

Based on available information on public safety incident area and first responder requirements, decision options in MBSFN or unicast were provided and resulting performance impacts were evaluated.

Next steps: explore MBSFN scheduling optimization in allocating MBSFN subframes and FRs receiving MBSFN or unicast transmission.

References

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