Service Continuity Using UE-to-Network Relays

David Griffith, Wireless Networks Division

National Institute of Standards and Technology
U.S. Department of Commerce

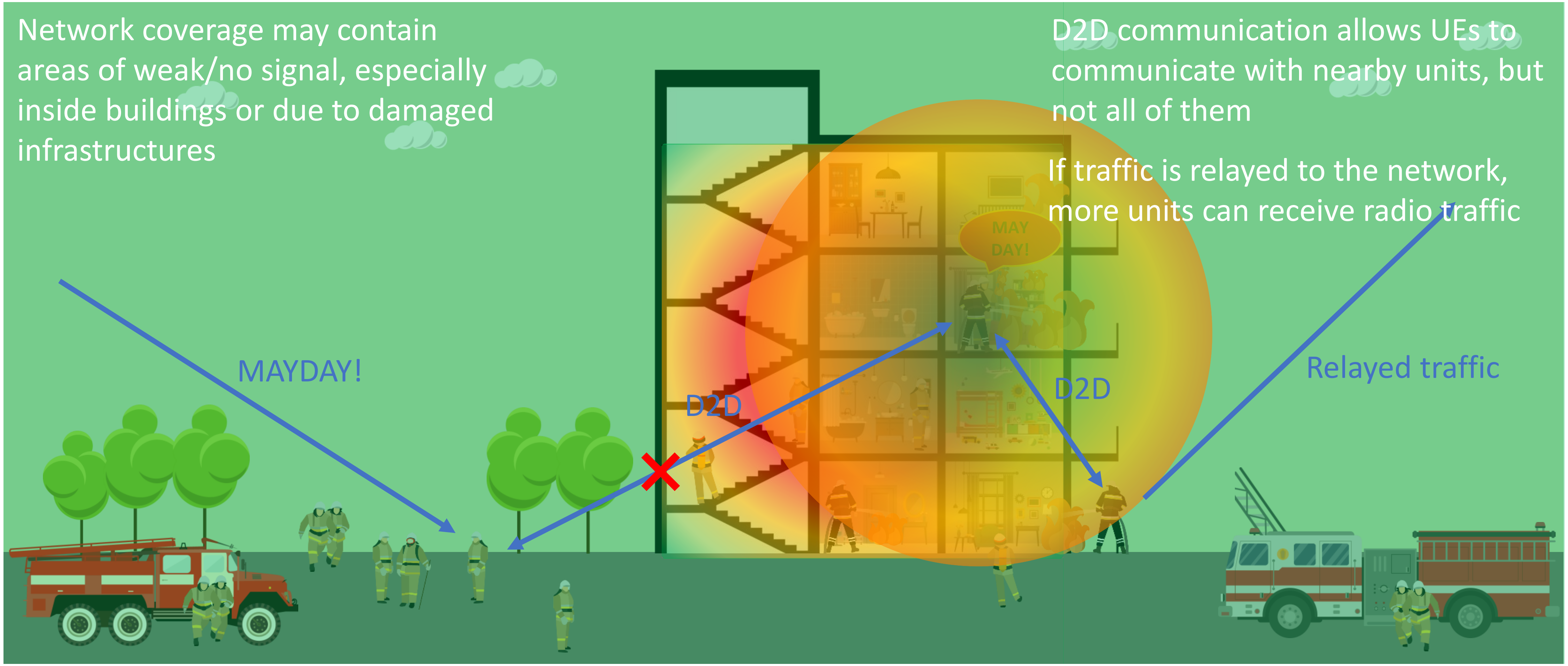
Communications Technology Laboratory

Motivations

Device to device (D2D) communication is critical when users are “out-of-coverage” from any cellular towers

In situations where some users are still within network coverage, D2D User Equipment (UE)-to-Network relays can be leveraged to extend and maintain connectivity to users near the cell coverage area

Partial Coverage Scenario



UE-to-Network Relay Functions

Relay Discovery and Selection

A UE losing connectivity with the network needs to discover the Relay UEs in proximity and select one to use

Relay Connection Establishment

The Remote UE exchanges signaling messages to establish a secure one-to-one link with the Relay UE

Relay Communication

The Relay UE performs IP-level forwarding of packets between the network and the Remote UE

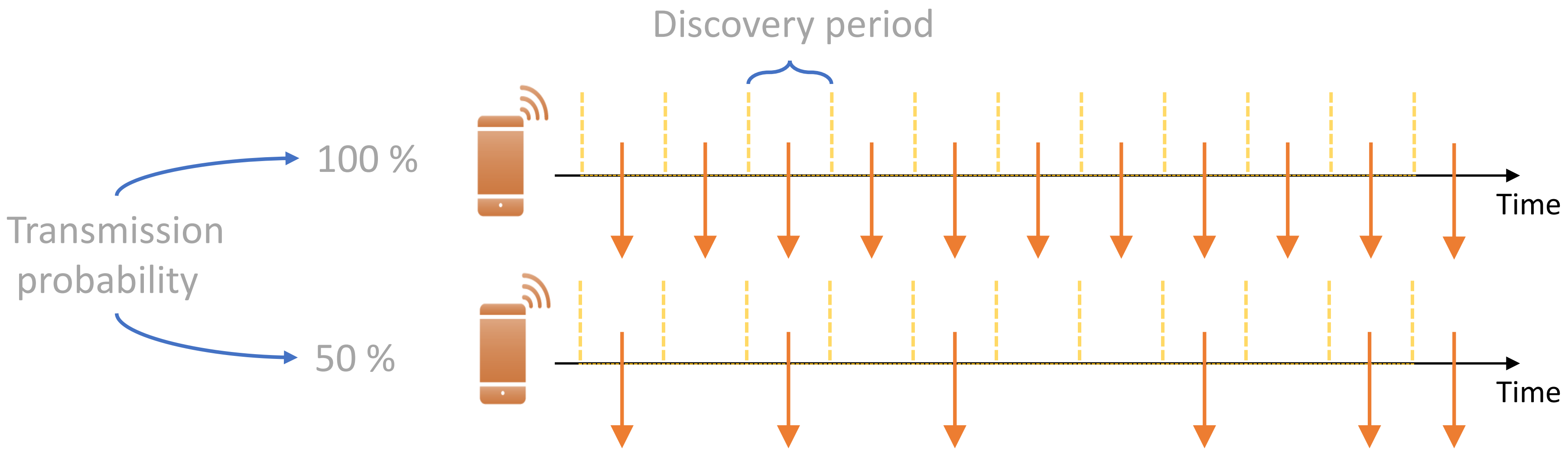
How long will the process take?
What is the impact on the user experience?
What are the major factors impacting performance?

Relay Discovery and Selection

Which discovery method to use?
How many relays can be discovered?
Which relay to select?

Relay Discovery Protocol Operation

- Discovery message transmission
  - Periodical (from 0.32 s up to 10.24 s)
  - Use transmission probability
  - Select resource randomly



Relay Discovery Protocol Challenges

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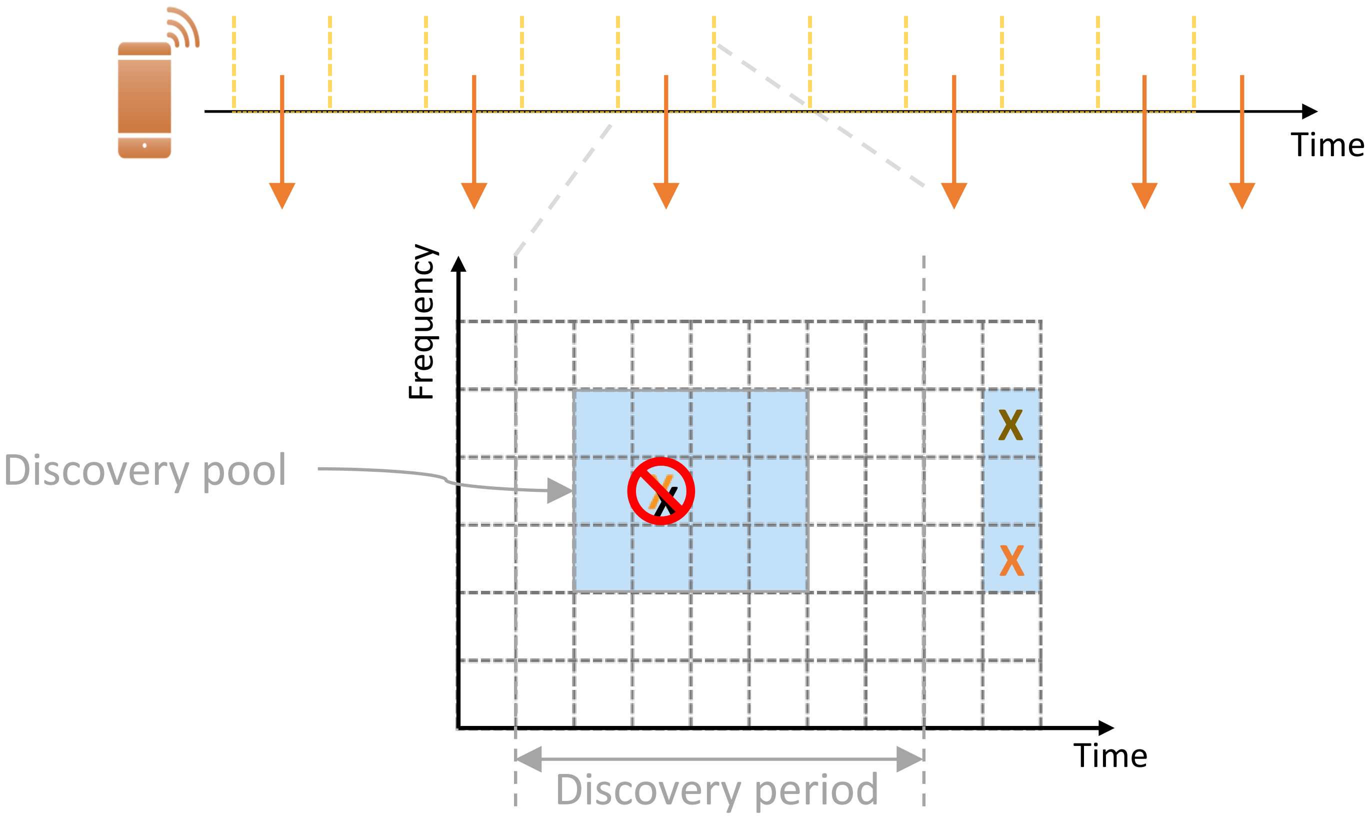
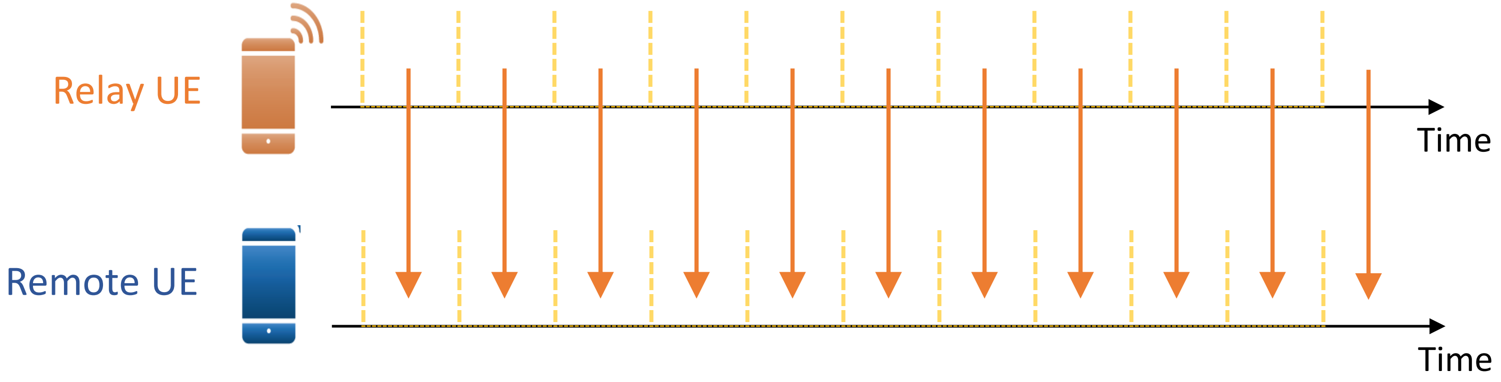
- Performance constraints / potential problems
  - Collisions
  - Half-duplex

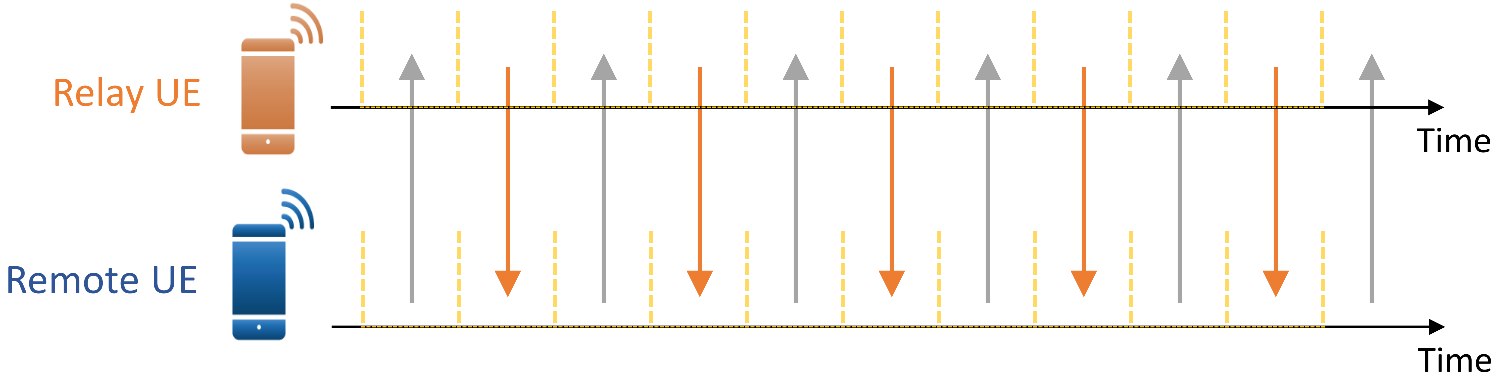


Relay Discovery Modes

Model A : Relay Announcement

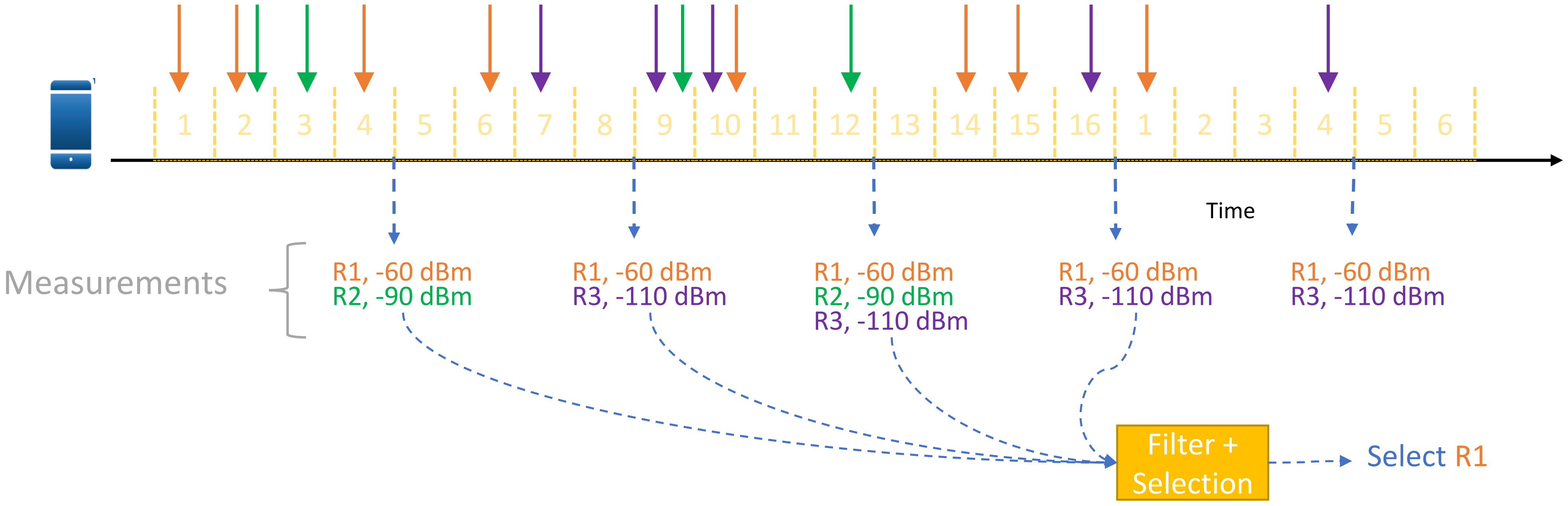


Model B : Relay Solicitation (Remote UE) - Relay Response (Relay UE)



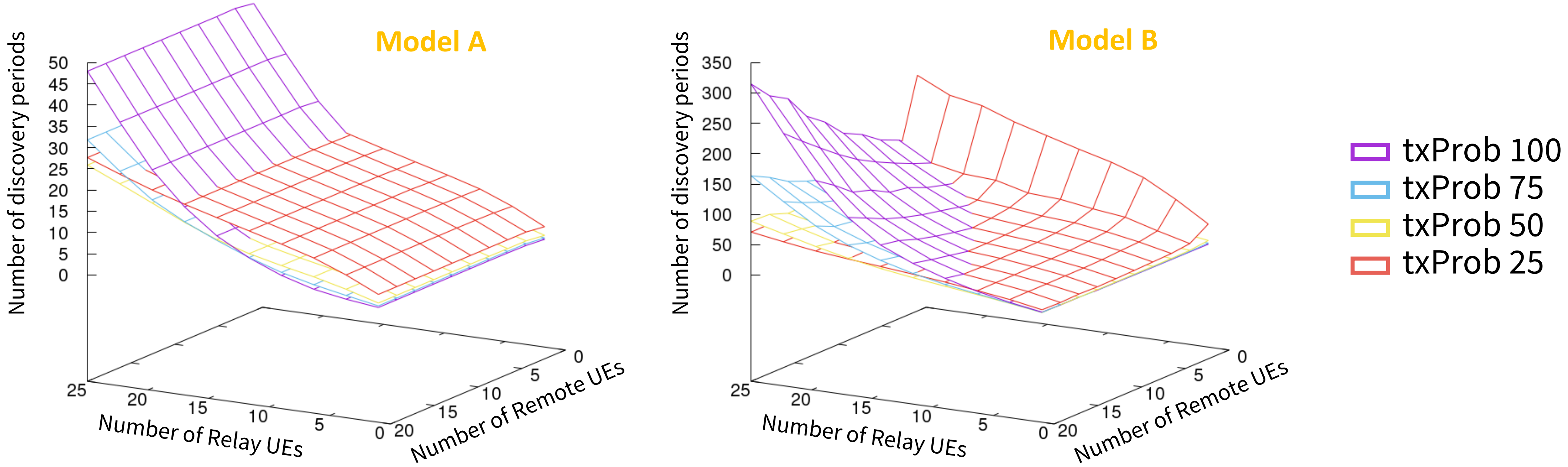
Relay Selection Process

- Search for candidate relay UEs every discovery period
- Measurement of the candidate relays every 4 discovery periods
- Evaluation of the candidate relays within 16 discovery periods



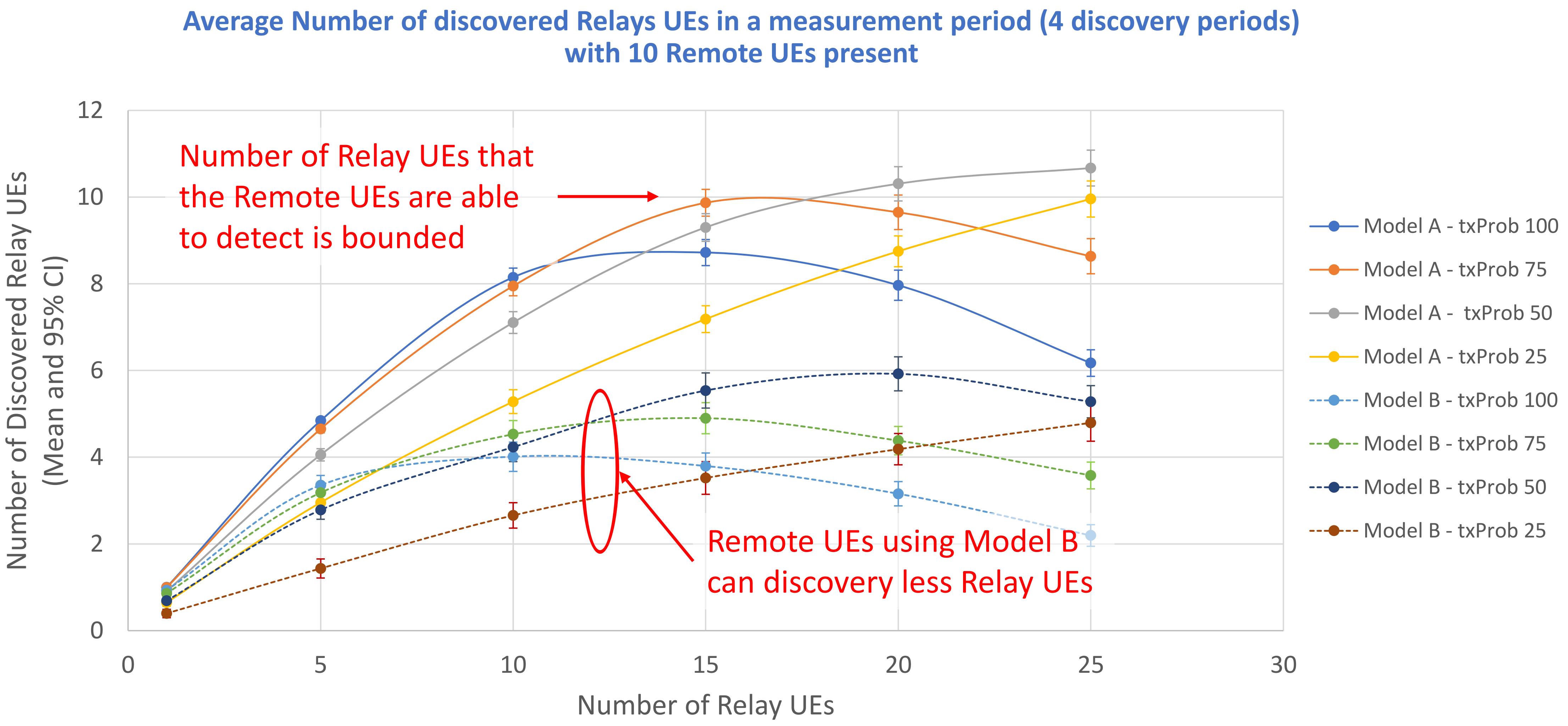
User Density Impacts Discovery Time

Number of discovery periods needed for All Remote UEs to discover all Relay UEs

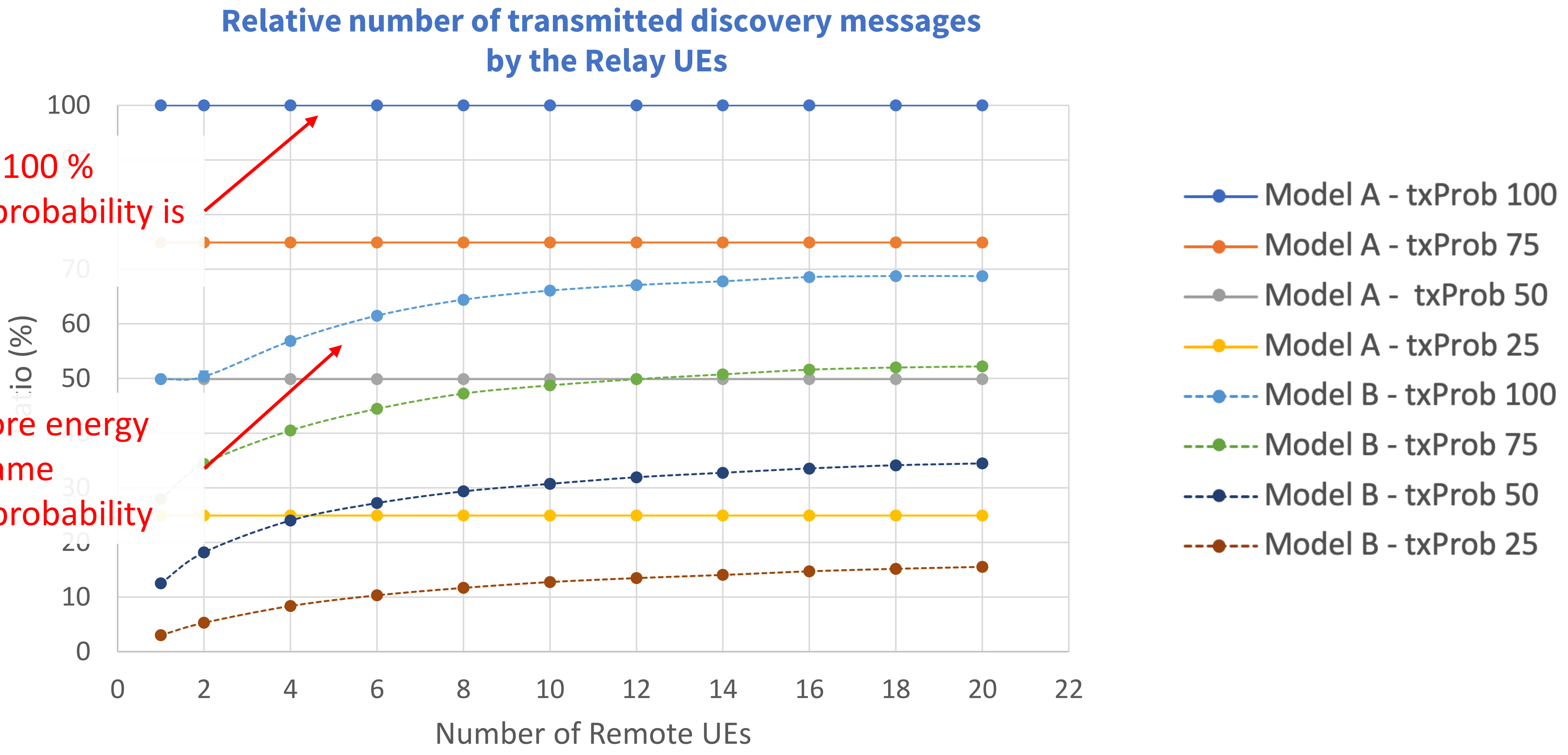


- Only the number of Relay UEs affects the discovery time.
- Both the number of Relay UEs and number of Remote UEs affect the discovery time

Impact of Discovery on the Relay Selection



Discovery Model Affects Power Usage



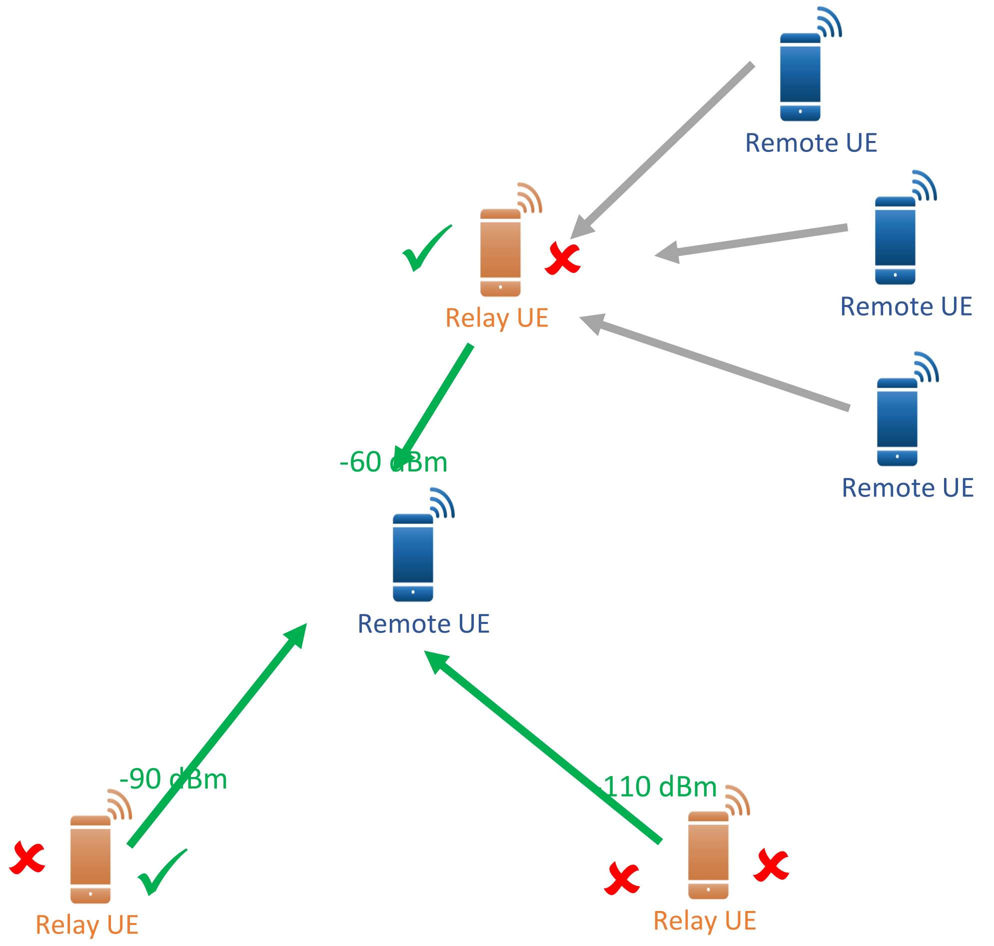
Model A with 100 % transmission probability is the worst

Model B is more energy efficient for same transmission probability

Selection Algorithm

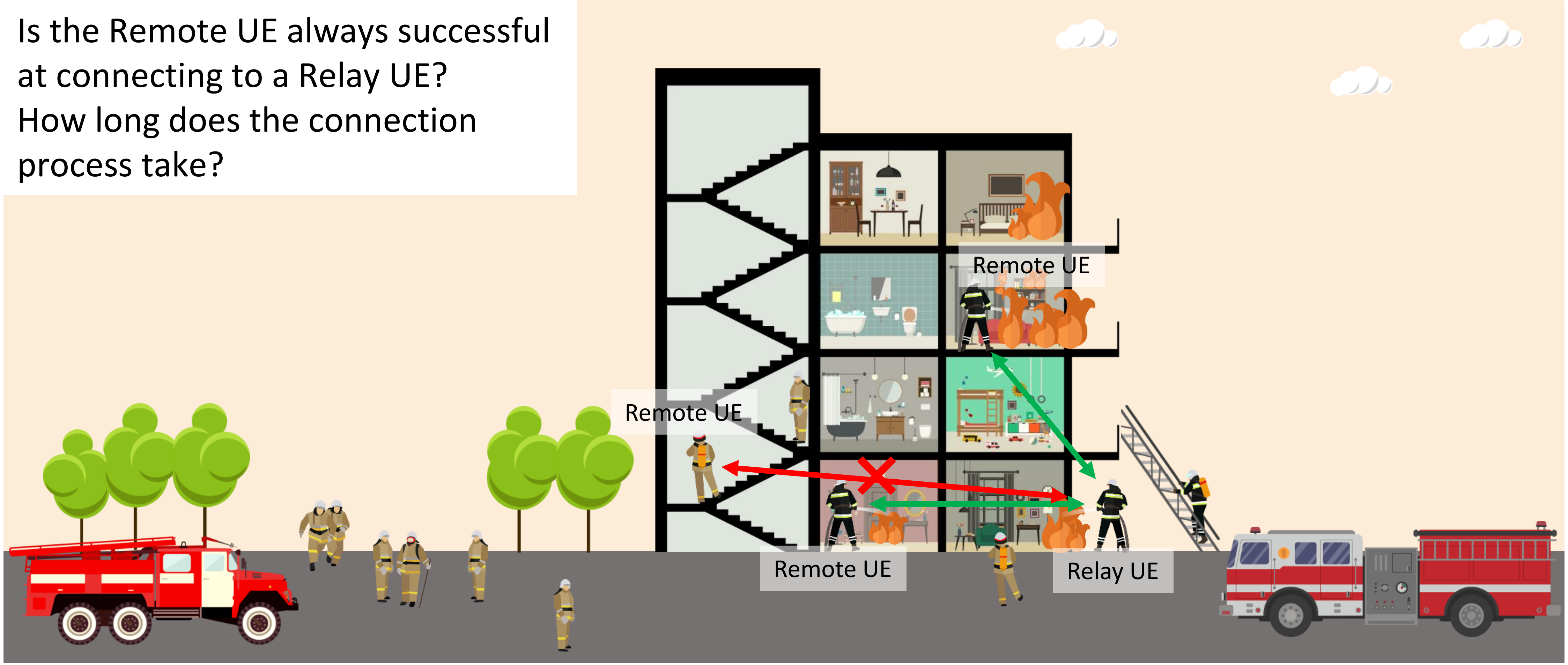
- Relay discovery affects the choices available to the Remote UEs

- Enhancing information available during the discovery allows to better selection
  - Load
  - Battery level
  - Achievable data rate



Relay Connection Establishment

Is the Remote UE always successful at connecting to a Relay UE?
How long does the connection process take?

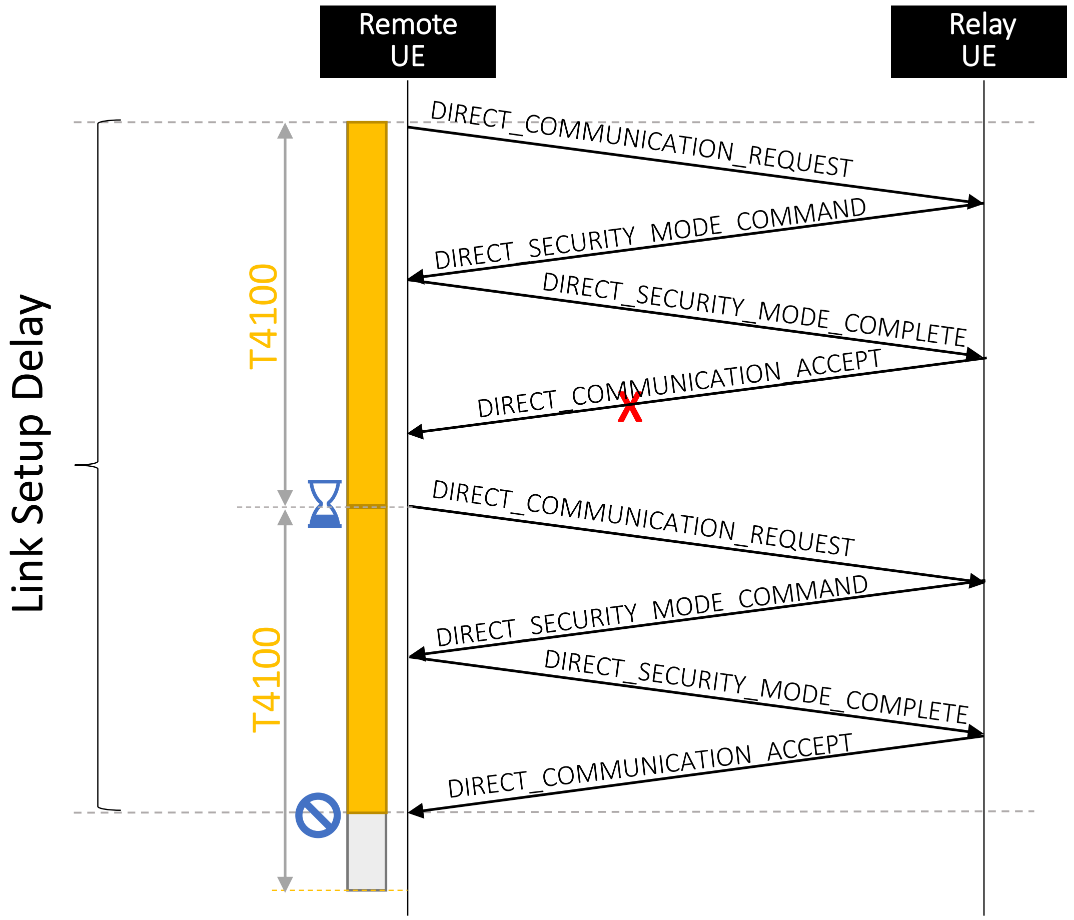


Relay Connection Establishment

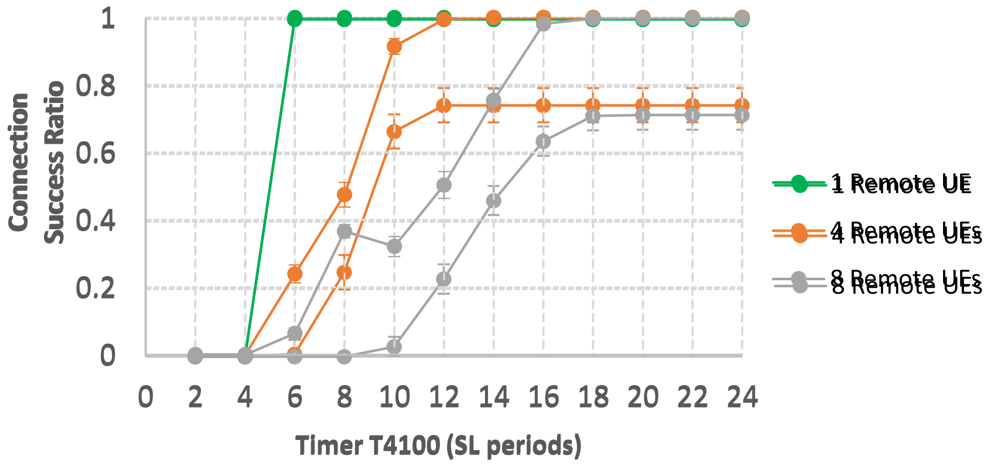
- Direct Communication Link Setup requires signalling between the Remote UE and the Relay UE
- If messages are lost, recovery mechanisms are available based on the following parameters:
  - Duration of Direct Communication Request retransmission timer (T4100)
  - Maximum number of Direct Communication Request retransmissions upon expiration of T4100

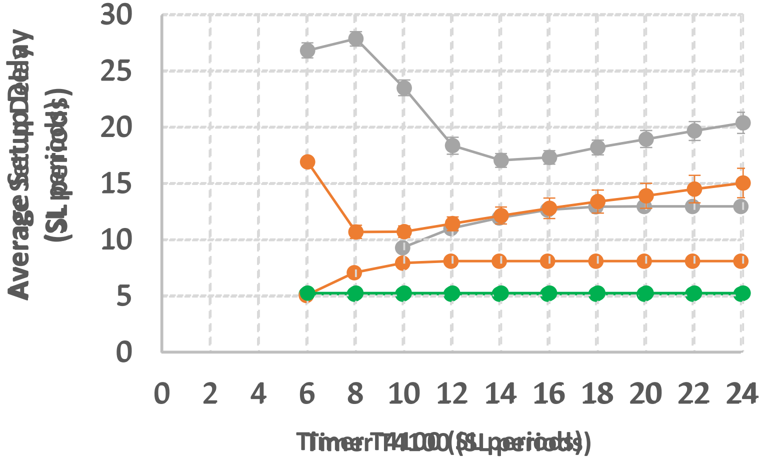
➔ How to configure those parameters?

Direct Communication Link Setup Procedure



Impact of T4100 and Retransmissions





Results with no background UL traffic

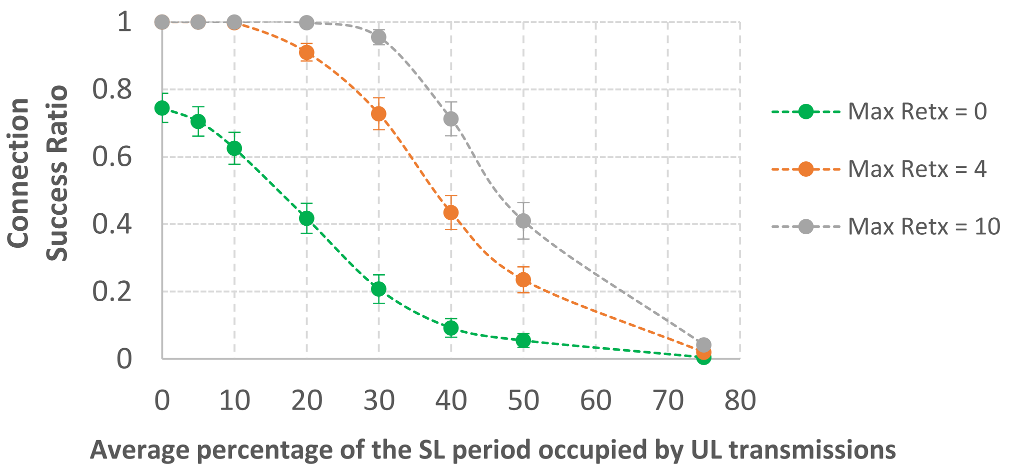
		SL period length	
		0.04 s	0.32 s
Number of periods	5	0.20 s	1.60 s
	10	0.40 s	3.20 s
	20	0.80 s	6.40 s
	30	1.20 s	9.60 s

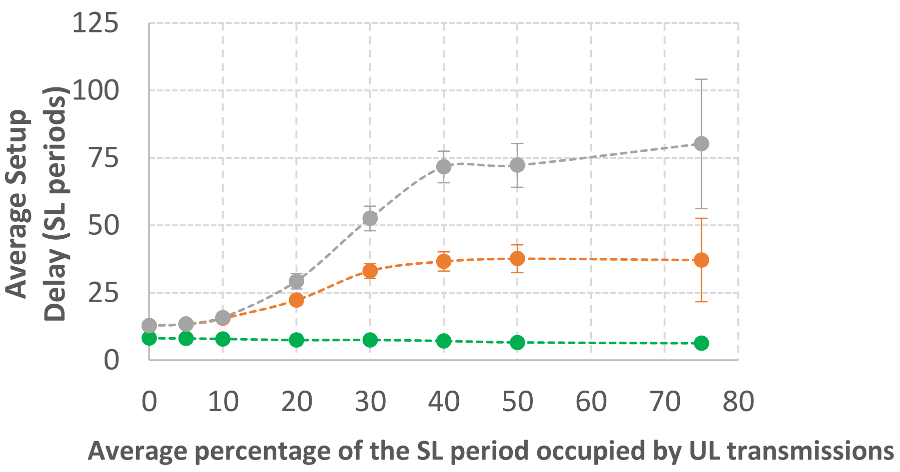
- The configuration of timer T4100 depends on the number of Remote UEs the Relay UE is communicating with in the Sidelink
- Retransmissions increase reliability but also latency

➔ Deployment must be considered when configuring protocols

Impact of Uplink Occupancy

4 Remote UEs and T4100 = 16 SL periods





Results with UL traffic and no scheduling coordination between UL and SL

Connection time		SL period length	
		0.04 s	0.32 s
Number of periods	10	0.40 s	3.20 s
	25	1.00 s	8.00 s
	50	2.00 s	16.00 s
	75	3.00 s	24.00 s

- Frequent uplink transmissions lower the sidelink connection reliability
- Increasing the number of retransmission can mitigate the loss but cause significant delays

➔ Coordination between uplink and sidelink resource allocation is needed

Relay Communication

What are the effects on application performance?
Will the user experience be affected?

Mission Critical Push-to-Talk (MCPTT)

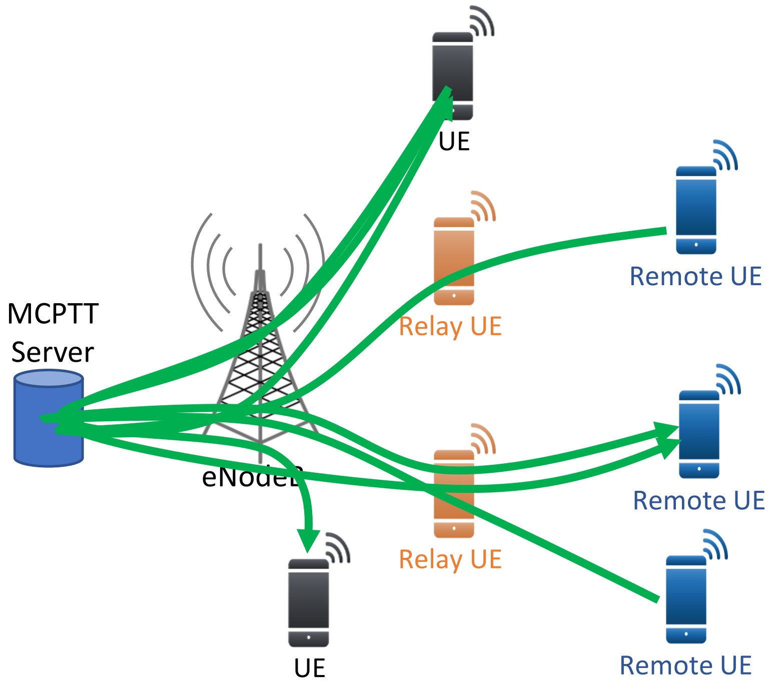
Performance Requirements

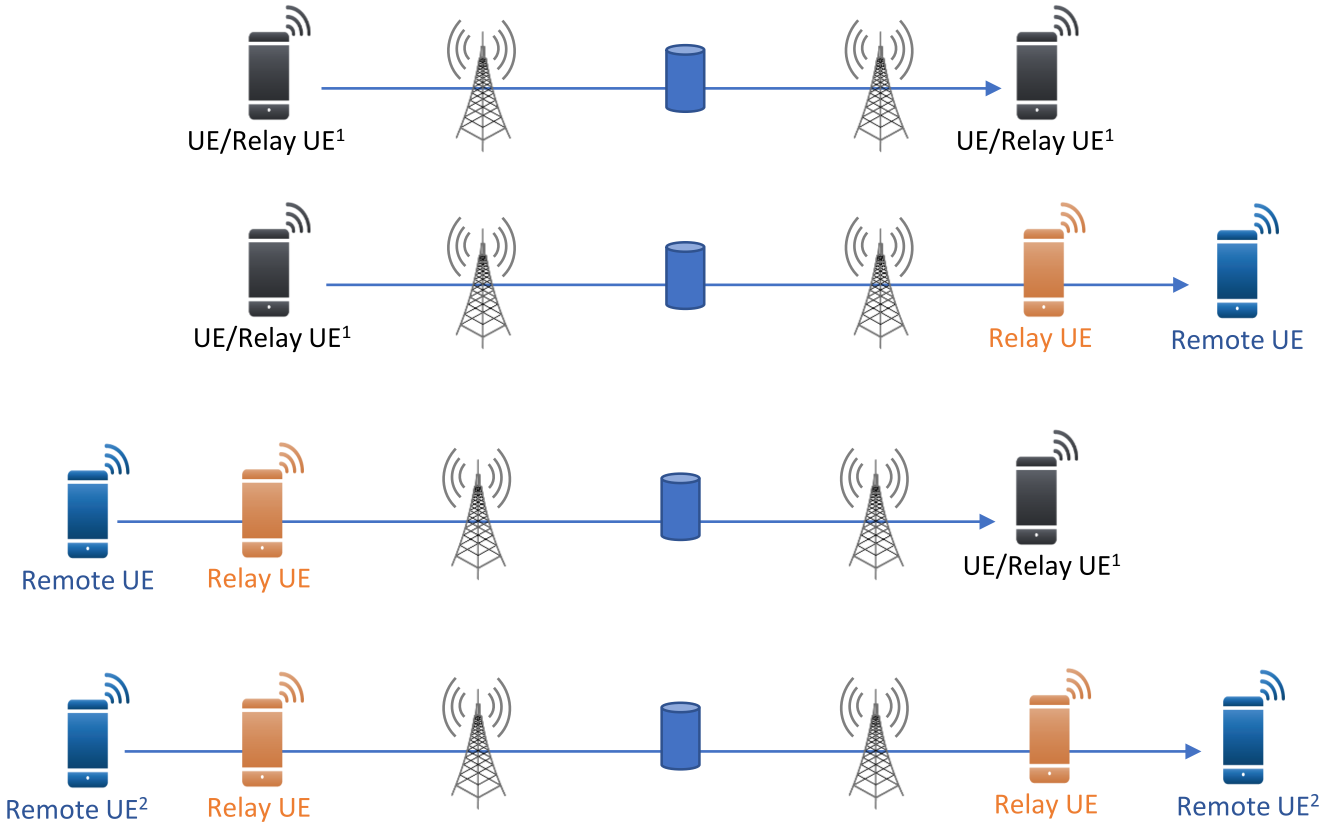
- 3GPP defines performance requirements for on network (TS 22.179)
  - **MCPTT Access time** (KPI 1) **less than 300 ms** for 95 % of all MCPTT Request.
  - **End-to-end MCPTT Access time** (KPI 2) **less than 1000 ms**
    - For users under coverage of the same network when the MCPTT Group call has not been established prior to the initiation of the MCPTT Request.
  - **Mouth-to-ear latency** (KPI 3) that is **less than 300 ms** for 95 % of all voice bursts.
  - Assumes negligible backhaul delay, max 70 % load, no transcoding

➔Can the same requirements be met when connected to a UE-to-Network relay?

Relay Communication Paths

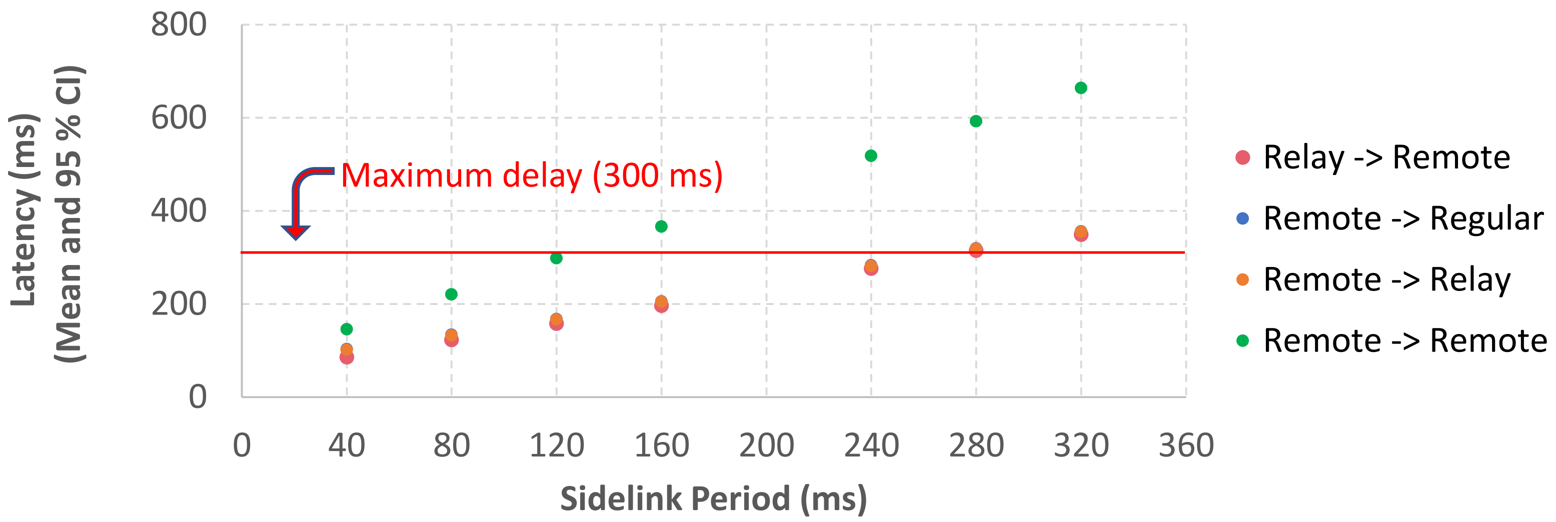
Scenarios with group communication





[1]While relay UEs are in coverage, delays to/from a relay UE might differ from that of a non-relay UE
[2]Performance will change whether the transmitter and receiver remote UEs are connected to the same relay or not

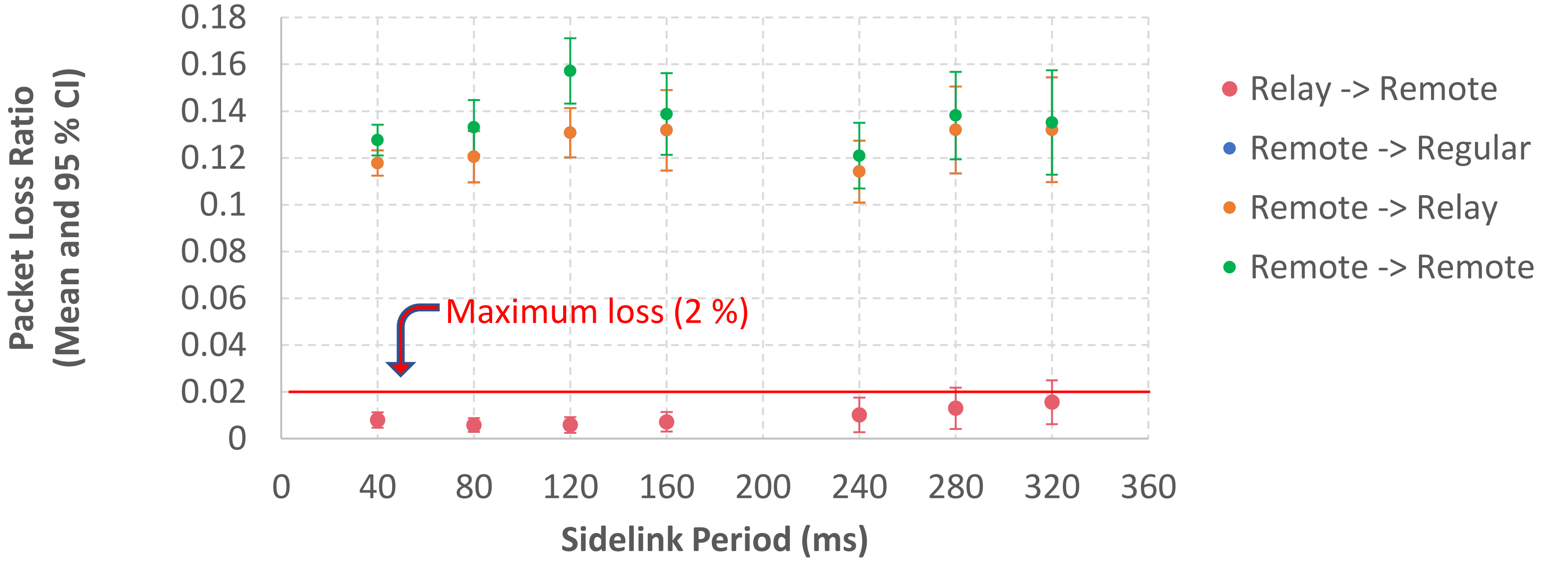
Impact of Sidelink on Mouth-to-Ear Latency



- Performance shown are for a network where only the media traffic is carried (no other load on the network)
- When a Remote UE is involved, the higher the sidelink period, the larger the latency

➔ Sidelink period configuration must be configured considering end-to-end packet delay requirements

Impact of Sidelink on Packet Loss

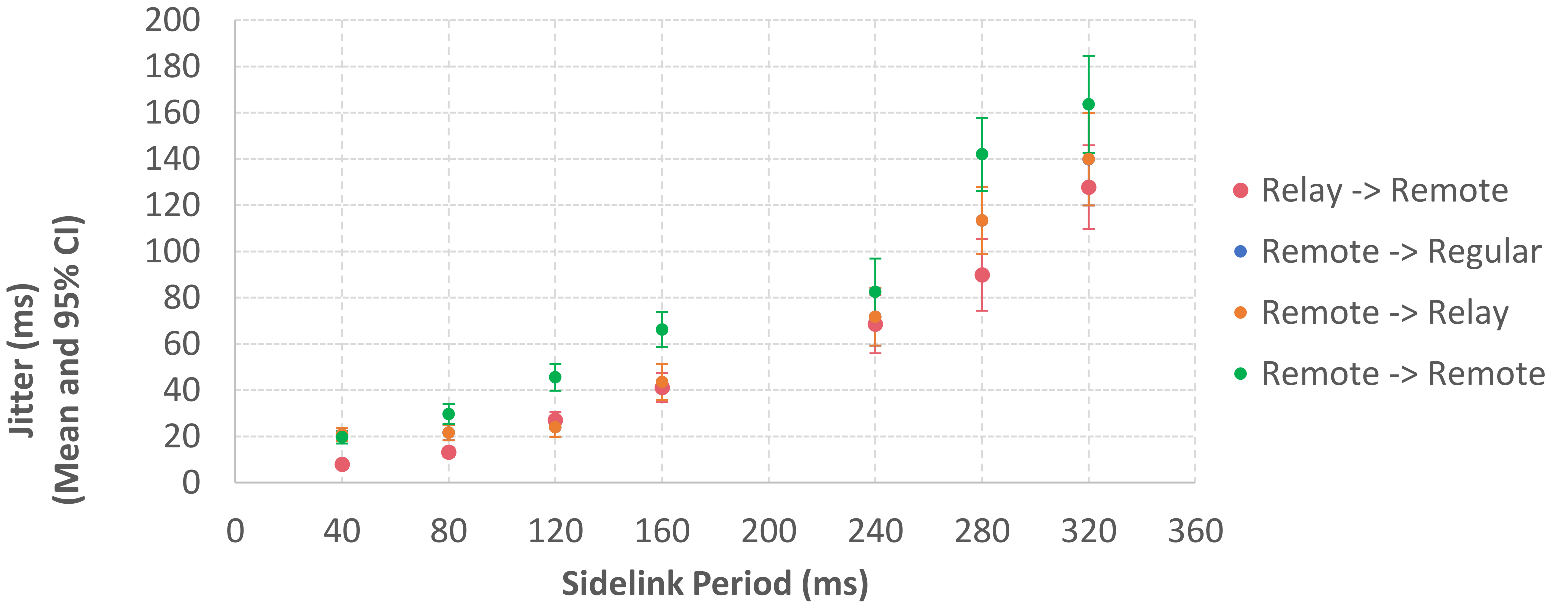


- Loss for Relay UE to Remote UE traffic under the threshold
- Excessive packet loss is observed when the transmitter is a Remote UE

➔ Sidelink period duration does not have a significant effect on the packet loss

➔ Coordination between uplink and sidelink resource allocation is needed

Impact of Sidelink on Packet Jitter



- Jitter is higher for Remote UE to Remote UE communication since sidelink is used twice

➔ Sidelink period duration has a direct impact on the packet jitter

Lessons Learned

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- UE-to-Network relays can help maintain connectivity for UEs losing coverage while in proximity of other UEs that are still in coverage
- Preliminary results show that performance are sensitive to several factors including:
  - Number of devices that can act as Relay UEs
  - Number of devices communicating with the Relay UEs
  - Sidelink configuration
  - Traffic load
- Users may notice some service degradation under certain conditions compared to on-network
- Our work will provide guidelines to configure the resources allocated to D2D and the protocol configurations to ensure proper operations

Areas for Future Investigation

- Relay activation
  - Algorithms to detect when/where a relay might be needed
- Interference mitigation
  - Reduce collisions between uplink and sidelink
- Impact on energy consumption
  - Quantify additional energy cost to the relay nodes
- Protocol configuration
  - Guidelines for configuring timers and maximum number of retransmissions (i.e., keep alive, failure recovery)

D2D Related Publications

NIST

1. S. Gamboa, R. Thanigaivel, R. Rouil, "*System Level Evaluation of UE-to-Network Relays in D2D-enabled LTE Networks*", submitted to 2020 IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)
2. J. Wang, R.Rouil, F. Cintrón, "*Distributed Resource Allocation Schemes for Out-of-Coverage D2D Communications*", submitted to 2019 IEEE Global Communications Conference (GLOBECOM)
3. S. Feng, H. Choi, D. Griffith, R. Rouil, "*On Selecting Channel Parameters for Public Safety Network Applications in LTE Direct*", submitted to 2019 IEEE Global Communications Conference (GLOBECOM)
4. A. Ben-Mosbah, D. Griffith, and R.A. Rouil, *"Enhanced Transmission Algorithm for Dynamic Device-to-Device Direct Discovery"* 2018 IEEE Consumer Communications and Networking Conference (CCNC 2018), Las Vegas, Nevada, January 2018.
5. D. Griffith, F. Cintrón, A. Galazka, T. Hall, and R.A. Rouil, *"Modeling and Simulation Analysis of the Physical Sidelink Shared Channel (PSSCH)"* IEEE International Conference on Communications (ICC 2018), Kansas City, Missouri, May 2018.
6. J. Wang, R.A. Rouil, *"Assessing Coverage and Throughput for D2D Communication"* IEEE International Conference on Communications (ICC 2018), Kansas City, Missouri, May 2018.
7. A. Ben-Mosbah, D. Griffith, and R.A. Rouil, *"Enhanced Transmission Algorithm for Dynamic Device-to-Device Direct Discovery"* Presented at the 2018 IEEE Consumer Communications and Networking Conference (CCNC 2018), Las Vegas, Nevada, January 2018.
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9. J. Wang, R.A. Rouil, *"Assessing Coverage and Throughput for D2D Communication"* Presented at the IEEE International Conference on Communications (ICC 2018), Kansas City, Missouri, May 2018.

D2D Related Publications (cont.)

10. D. Griffith, "*Modeling Device-to-Device Communications for Wireless Public Safety Networks*," in IEEE 5G Workshop for Tactical and First Responder Networks, Johns Hopkins University Applied Physics Laboratory, 23 October 2018.
11. F. Cintron, *"Performance Evaluation of LTE Device-to-Device Out-of-Coverage Communication with Frequency Hopping Resource Scheduling"* NIST Interagency/Internal Report (NISTIR) 8220. July 23, 2018.
12. R. Rouil, F. J. Cintrón, A. Ben Mosbah, and S. Gamboa, "*Implementation and Validation of an LTE D2D Model for ns-3*," WNS3 2017, Porto, Portugal, June 13-14, 2017.
13. S. Gamboa, F.J. Cintrón, D. Griffith, and R. Rouil, "*Impact of timing on the Proximity Services (ProSe) synchronization function*", in IEEE Consumer Communications & Networking Conference (CCNC17).
14. D. Griffith, A. Ben-Mosbah, and R. Rouil, "*Group Discovery Time in Device-to-Device (D2D) Proximity Services (ProSe) Networks*", IEEE INFOCOM 2017 - The 36th Annual IEEE International Conference on Computer Communications.
15. A. Ben-Mosbah, D. Griffith, and R. Rouil, "*A Novel Adaptive Transmission Algorithm for Device-to-Device Direct Discovery*", in IEEE Wireless Communications and Networking Conference 2017 (WCNC17).
16. D. Griffith, F. Cintrón, and R. Rouil, "*Physical Sidelink Control Channel (PSCCH) in Mode 2: Performance Analysis*", 2017 IEEE International Conference on Communications 2017 (ICC 2017), Paris, France, 21-25 May 2017.
17. S. Gamboa, F.J. Cintrón, D.W. Griffith, R.A. Rouil, *"Adaptive synchronization reference selection for out-of-coverage Proximity Services (ProSe)"* 28th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Montreal, Canada, October 2017.
18. David Griffith and Fiona Lyons, "*Optimizing the UE Transmission Probability for D2D Direct Discovery*," 2016 IEEE Global Communications Conference (GLOBECOMM 2016), Washington, DC, 4-8 December 2016.
19. J. Wang and R. Rouil, "*BLER Performance Evaluation of LTE Device-to-Device Communications*," NIST Interagency/Internal Report (NISTIR) 8157, Nov. 2016.