3GPP TSG RAN #93
Electronic Meeting, Sep 13 - Sep 17,2021

RP-212396

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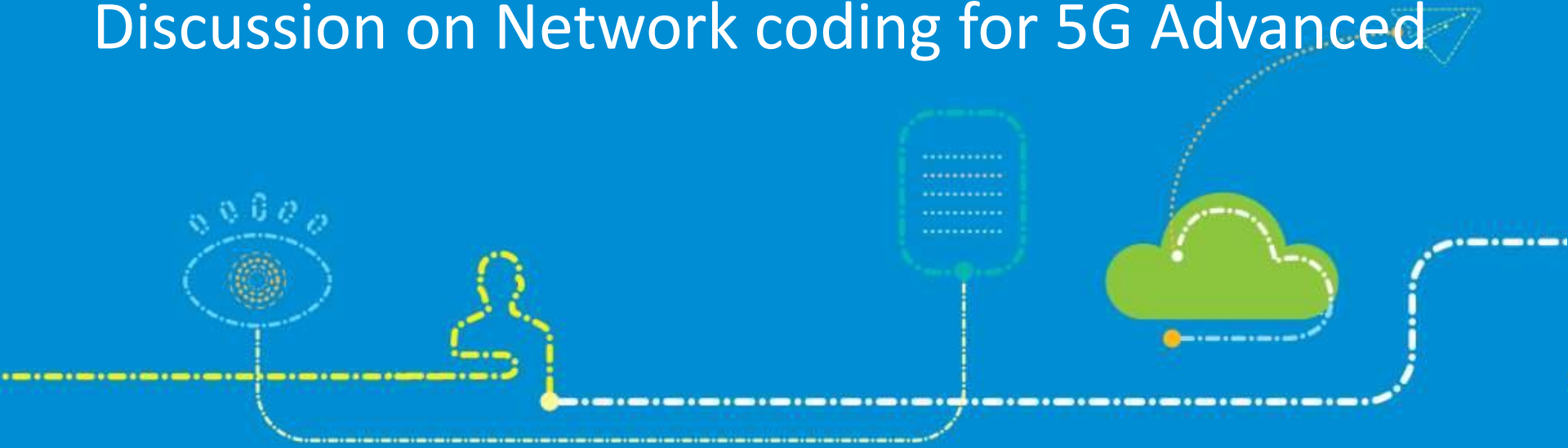
Discussion on Network coding for 5G Advanced



General description

- Due to the requirement of low latency and high reliability of some traffics, such as XR and URLLC, the ARQ functionality in RLC layer needs to be closed or limited, which leads to insufficient reliability.
- According to 5QI tables, there are many XR and URLLC traffics with high reliability, e.g. , PER from 10^{-3} to 10^{-8}. As a result, a possible alternative solution to ensure the reliability is FEC (forward error correction). In detail, network/packet coding can be introduced to derive coding diversity to improve the of reliability.
- According to the SLS results of different PER with the same PDB for a specific XR traffic shown in Figure 1, it is observed that capacity can be improved if the required PER is relaxed, which means that reliability and capacity are interchangeable.

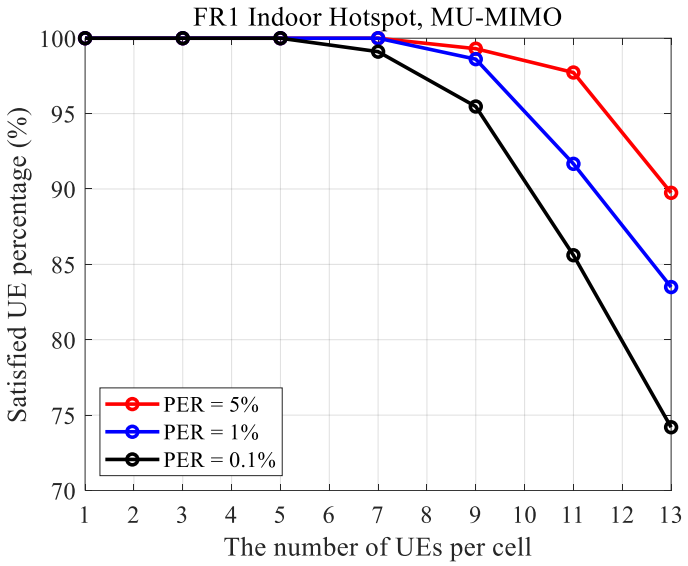


Figure 1 Number of satisfied UE with different PER requirements

(traffic model and simulation assumptions are provided in Appendix)

Scenarios of NC for URLLC traffic

- Packet duplication over multiple connections have been supported in Rel-16 for URLLC.
- In Rel-18, simple duplication can be substituted by duplication enhancement based on network/packet coding depicted by the Figure 2 for URLLC.
  - Step 1: one PDCP PDU packet can be split into K=2 source packets with equal size.
  - Step 2: the K=2 source packets can be encoded to derive additional M=2 parity packets.
  - Step 3: the K=2 source packets are transmitted in the first link, M=2 parity packets are transmitted in the second link. Different packets should be transmitted in the diversity way to ensure independence among packets.
  - Step 4: a UE receives packets from the first link and the second link. If the number of successfully received packets equals to or are larger than 2, K=2 source packets can be recovered to restore original data.

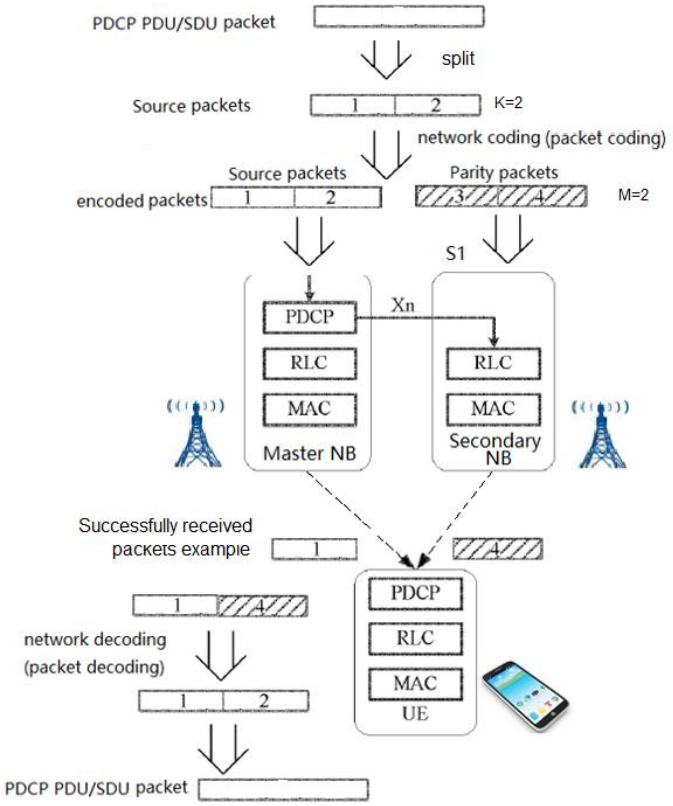


Figure 2 Example of network coding for URLLC traffic

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Motivations of NC for URLLC traffic

- Performance is compared between PDCP duplication and enhanced PDCP duplication with network coding.
- For legacy PDCP duplication, one PDCP packet is transmitted in the first link, the duplicated PDCP packet is transmitted in the second link. It is assumed that PER(packet error rate) of each transmission packet of both links is p, then the failure rate of the PDCP packet in the receiver is $p*p = p^2$.
- For enhanced PDCP duplication with split and network coding depicted in Figure 2, it is assume that PER of each packet of both links is p, then the failure rate of the PDCP packet in the receiver is $4* p^3*(1- p) + p^4 \approx 4* p^3$.
- ***Observation:*** *PDCP duplication based on split and network coding can improve reliability as shown in Figure 3.*

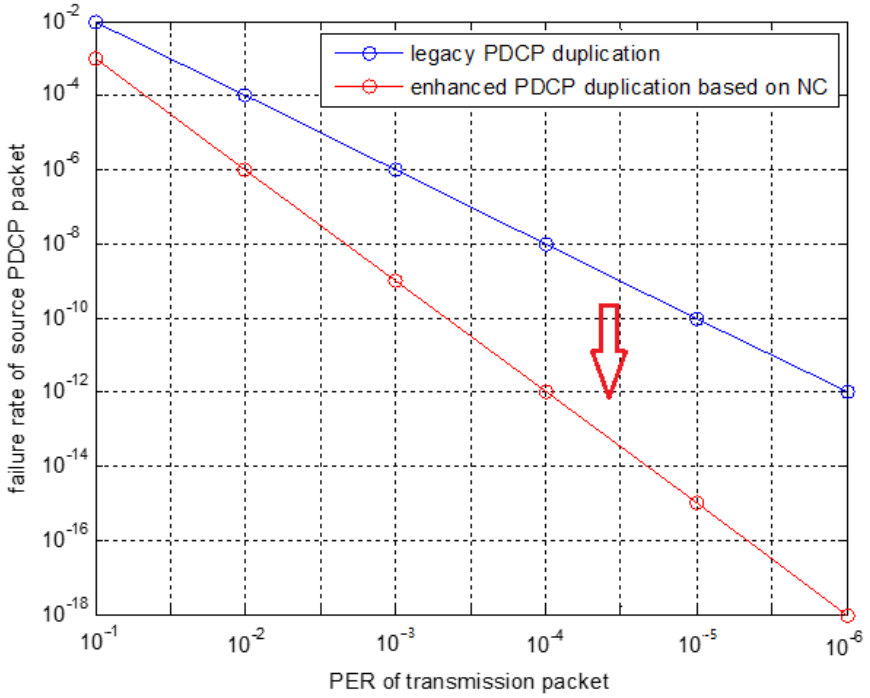

Figure 3 Performance comparison between legacy PDCP duplication and enhanced PDCP duplication

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Scenarios and Motivations for XR traffic

- **Motivation:** Network/packet coding can be used to further increase the reliability or data transmission efficiency for multiple connections. This has potential benefit especially for XR and IIOT scenarios where there are massive IIOT users.

- In Rel-18, simple duplication can be substituted by network/packet coding duplication as depicted by Figure 4 for XR traffic, wherein all parity packets can be sent in the second link.

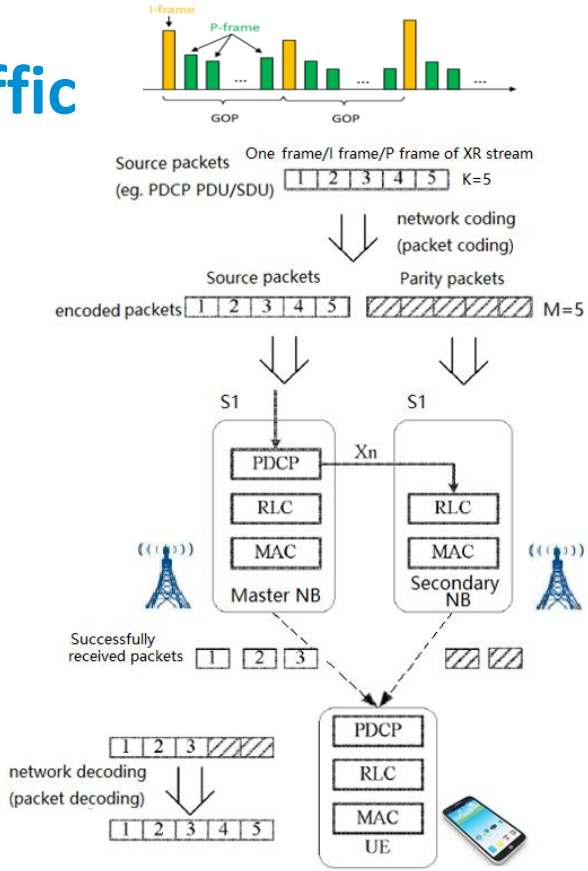

Figure 4 Example of network coding for XR traffic

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Reliability evaluation for Network/packet coding(NC)

- Evaluation and formula is conducted to compare the reliability performance comparison between simple duplication and NC based duplication in Figure 5, wherein the failure rate of one PDCP PDU/SDU at a given pair of the packet loss rate of the first link is Pe1 and the packet loss rate of the second link is Pe2. Note that it is proved that formula is aligned with simulation well.
- Formula: for legacy duplication, FailureRate = Pe1*Pe2;

  for enhanced duplication based on NC, FailureRate = $\sum_{N1+N2>N} C_N^{N1}\left(Pe1^{N1}\cdot(1-Pe1)^{N-N1}\right)\cdot C_N^{N2}\left(Pe2^{N2}\cdot(1-Pe2)^{N-N2}\right)$
- Simulation assumption:
  - K is the number of source packets which will be transmitted in the first link, e.g., K=5 in Page 7;
  - M is the number of parity packets which will be transmitted in the second link, eg M=5 in Page 7;
  - Pe1 is the packet loss rate of the first link, e.g., Pe1=3/5=0.6 in Page 7;
  - Pe2 is the packet loss rate of the second link, e.g., Pe2=2/5=0.4 in Page 7;
  - Failure rate is defined as the decoding error rate of one PDCP PDU/SDU（one frame/I frame/P frame of one XR stream）;
  - N1 is the number of erroneous packets in the first link; N2 is the number of erroneous packets in the second link.
  - Optimal erasure codes are assumed and link simulation based on BEC channel are used;
  - In the simulation assumption, each packet in the first link is independent but has the same packet loss rate Pe1. That is to say, whether each packet is received wrongly is simulated and determined by an independent random variable with even distribution. Hence, N packets have N independent variables. Meanwhile, each packet in the second link is independent but has the same packet loss rate Pe2.

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Reliability Comparison – Simple Duplication vs NC based Duplication

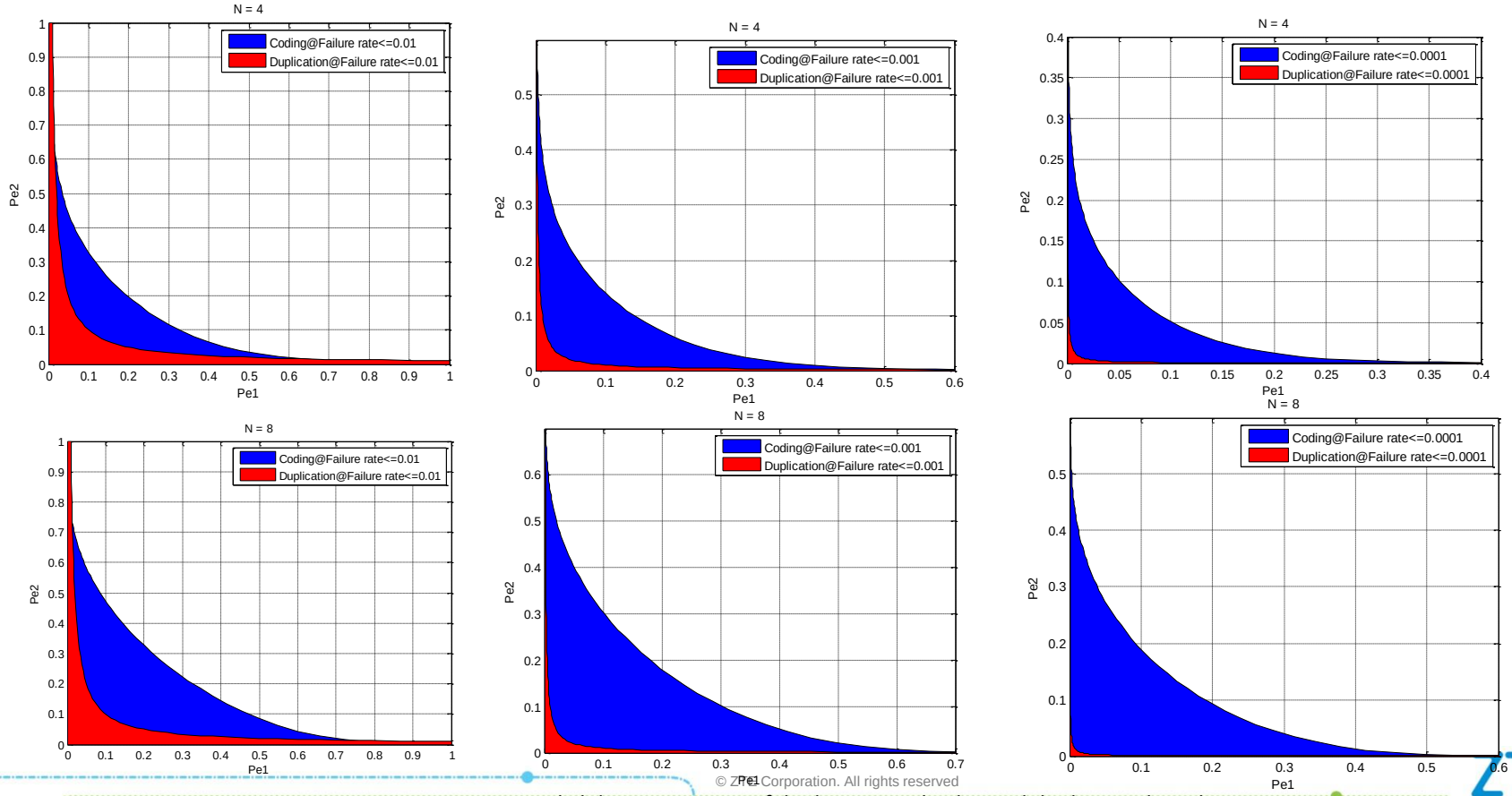

Figure 5 Reliability comparison of duplication and enhanced duplication based NC

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Evaluation Results Overview

The simulation results are summarized as follows:

- ***Observation 1:*** *According to the failure rate at a given pair of Pe1 and Pe2, NC based duplication has much better reliability performance than simple duplication over dual connections due to FEC coding gain.*
- ***Observation 2:*** *The performance gap between simple duplication and NC based duplication has become larger when N increases, which means that NC based duplication is very useful for large packet traffic, e.g., XR traffic with high date rate requirement.*
- ***Observation 3:*** *The performance gap between simple duplication and NC based duplication becomes larger when target Failure Rate increases, which means that NC based duplication is very useful for high reliability scenarios with very low PER requirements and a limited PDB.*
  - *Notes 1: The packet loss rates of the first/second links(Pe1/Pe2) are determined not only by channel capacity of links, but also the network traffic control within a certain time window, e.g., PDB.*
  - *Notes 2: In industrial scenarios, network/packet coding has been applied in the multiple connections, e.g., the aggregation of multiple TCP links, which can improve the reliability, throughput and coverage.*

Proposal: *Network coding based PDCP duplication can be introduced in Rel-18.*

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Erasure codes for Network/packet coding(NC)

- Network/packet coding can be implemented by erasure codes with BEC channel, such as Reed-Solomon codes, Fulcrum network codes, Raptor codes, RaptorQ codes, Low density generator matrix codes and so on.
- For erasure codes, there are the optimal erasure codes. For the optimal erasure codes, in the encoding stage, erasure codes encode K data elements to generate additional M parity elements via arithmetics over Galois finite field. These K + M elements that are encoded together collectively constitute a codeword, promising that any K out of the K+M elements within a codeword suffice to reproduce the original K data elements. In other words, erasure codes can tolerate any M element failures within each codeword.
- It is suggested that K is a small number from 2 to 16, which can ensure very low encoding/decoding complexity. What is more, software implementation based on CPU or GPU is very friend to 5G industry.

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objectives

- Study of layer(s) on which network coding should be performed including study of protocol stacks of network coding based on PDCP duplication, e.g., network coding layer between RLC and PDCP (RAN2)
- Identification and evaluation of scenarios (e.g. URLLC, DC, IAB, etc.) where Layer-2 packet coding can be introduced with benefits including PDCP duplication enhancements based on network coding
- Identification of architecture and protocol impacts for applying Layer-2 packet coding to various scenarios.

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Appendix

Simulation Assumptions

Table A.1 simulation parameters for FR1 DL

Parameters	Value
Scenario	Scenario-1: Indoor Hotspot 12 nodes in 50 m x 120 m
Inter-BS distance	20m
Carrier frequency	4 GHz
Duplex Mode / Simulation bandwidth	100 MHz
SCS	30KHz
TDD pattern	DDDSU
BS Antenna Configuration	32 Tx antenna ports, and (dH, dV) = (0.5λ, 0.5λ); 32TX:(M, N, P, Mg, Ng; Mp, Np) = (4,4, 2, 1, 1; 4, 4); The antenna tilt is 90 degrees.
UE Antenna Configuration	4 Rx antenna ports, and Panel model 1: dH = 0.5λ 4 Rx: (M, N, P, Mg, Ng; Mp, Np) = (1,2,2,1,1; 1,2);
Transmit Power	24 dBm per 20M at TRP, and 23 dBm at UE
BS Height	3 m
UE Height	1.5m
Antenna Element Gain	5dBi for BS and 0 dBi for UE
Receiver Noise Figure	5 dB for BS and 9 dB for UE
UE distribution	100% of users are indoor Use 3km/h for modeling fading channel
Number of UEs per cell	up to 13
Scheduling Algorithm	MU-MIMO+ PF
HARQ/repetition	HARQ retransmission
Channel estimation	Realist
Target BLER	10% for first transmission
PHY processing delay	UE PUSCH processing Capability #1,N1=10
PDCCH overhead	1/7(2symbols per 14symbol)
DMRS overhead	1 symbol per 14symbol
BS receiver	MMSE-IRC

Traffic Model

Parameters	Values
Data rate	30Mbps
Periodicity	60fps
Mean packet size	62500 Byte
Standard deviation	6563 Byte
Maximum packet size	93750 Byte
Minimum packet size	31250 Byte
Packet delay budget	10ms

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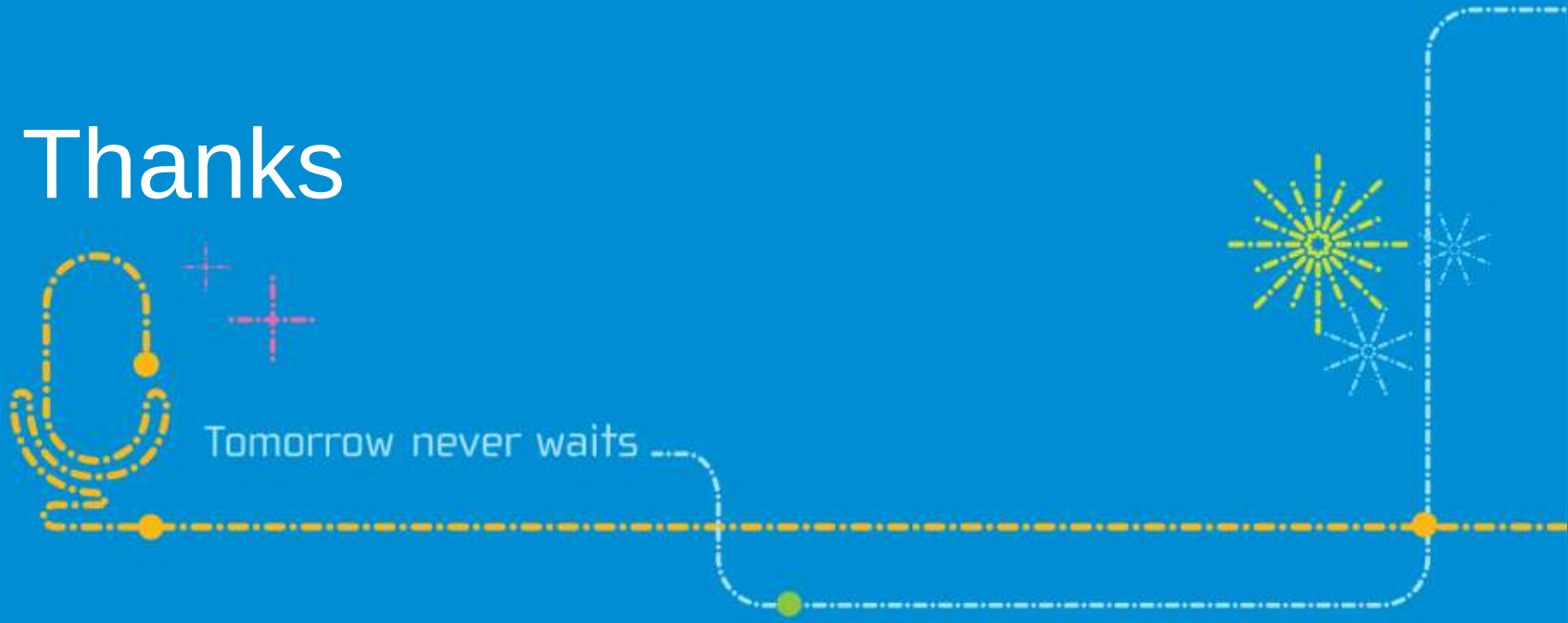
Thanks