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Novel Approach for Prioritization of TCP Acknowledgements in Beyond 4G and 5G network

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Problem Statement

- Evolution in cellular wireless communication and standardization has brought out technological advancements in physical and medium access layer protocol to scale data rate on air interface like LTE or NR 3GPP standards by 10x to 100x compared to older technologies

- However, there is not much thrust given on the interworking with TCP/IP, resulting in poor user experience, as a similar scale of improvement is not seen at application level

- The problem related to delayed TCP acknowledgment acts as a bottleneck at application level, which in turn results in low uplink or downlink throughput at User equipment

- Each layer in 3GPP LTE or NR, i.e. MAC, RLC and PDCP has its own control packet, which has more priority than the data packets and are prioritized while handling UL grant.

- Link layer treats TCP ACK packet as a normal data packet and is not given any preferential treatment in the current literature

Problem Statement

- When eNodeB scheduler allocates Uplink (UL) grant, i.e., frequency-time resource, the UE prepares a MAC transport block using RLC PDUs

- In case of bi-directional traffic scenario with high UL traffic, the sequence number (SN) allocated to the TCP ACK for corresponding downlink (DL) packet will be after large gaps, i.e. farther in SN space.

- This TCP ACK will be sent only after all the earlier UL data packets (with allocated SNs) are sent; this delay in sending the TCP ACK will lower the DL TP, as DL packets will be sent slowly from the server side

- In this paper, two novel solutions are presented to address prioritization of TCP ACKs by SN reservation and SN space management in simultaneous UL/DL traffic scenarios while maintaining low complexity.

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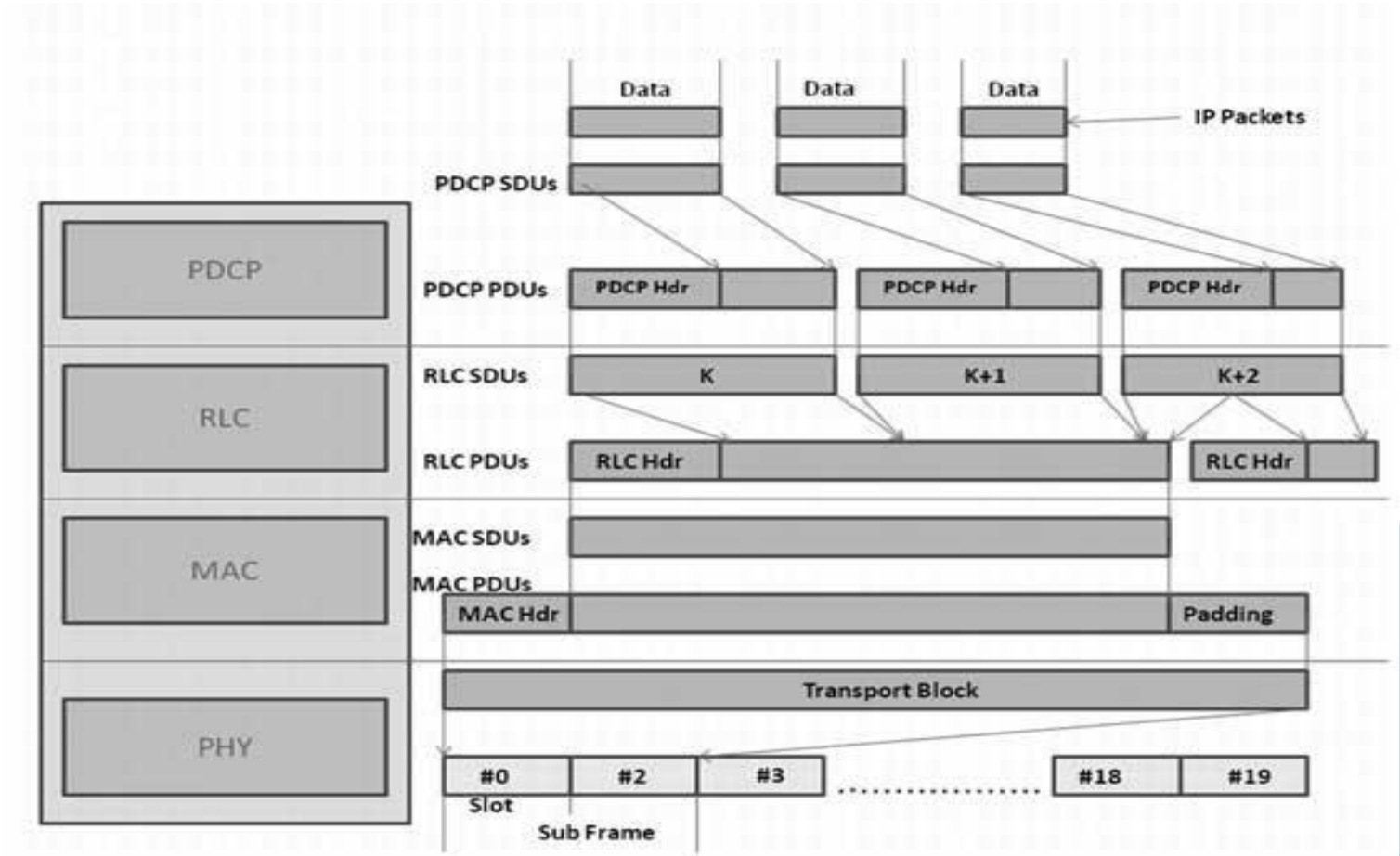
Problem Statement



Solution

- To solve the aforementioned problem of delayed TCP ACK, this paper presents two novel solutions

1. SN Reservation by

   – Creating “hole-SN” to be utilized by TCP ACKs

   – SN reservation for TCP ACKs with advance packet creation scheme

2. SN space division for handling data packet and ACKs separately

Proposed Schema-1a: Reserve SN

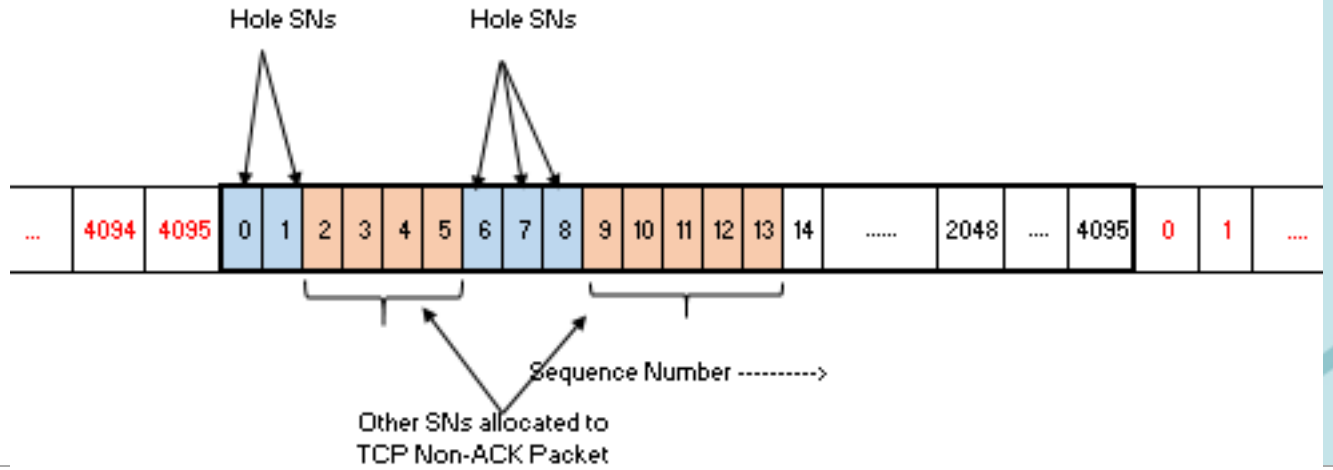
- In this proposal, one or more SN numbers are reserved in the PDCP SN or RLC SN space at regular or adapted intervals of UL SN space. These are called ‘hole SNs’
- When a TCP ACK arrives, these hole-SNs are assigned to them for creating the corresponding PDCP or RLC PDU.
- This makes sure that the earlier SN(s) in UL SN space is assigned to TCP ACKs and hence will be transmitted earlier on UL grant reception.
- The rate at which the “number of hole-SNs reserved for TCP ACK packets” and “ the internal in the UL SN space when the first hole-SN starts” is either static or dynamically adaptive.
- Since the proposed solution allocates relatively earlier SNs to the TCP ACK packets, it reduces the delay in TCP ACK sending for majority of the TCP ACK packets.

Proposed Schema-1a: Reserve SN

- In case hole-SNs being unused, LTE/NR network can face PDCP reordering delay in Dual Connectivity (DC) scenario.

- Therefore, this scheme addresses the possible reordering delay problem by using one of the procedures –
  - “the previous or next PDCP SDU will be mapped to the hole-SN and transmitted; the duplicated SDU will be automatically dropped at the receiver”;

  - or “PDCP data headers are mapped to the hole-SNs and transmitted”.



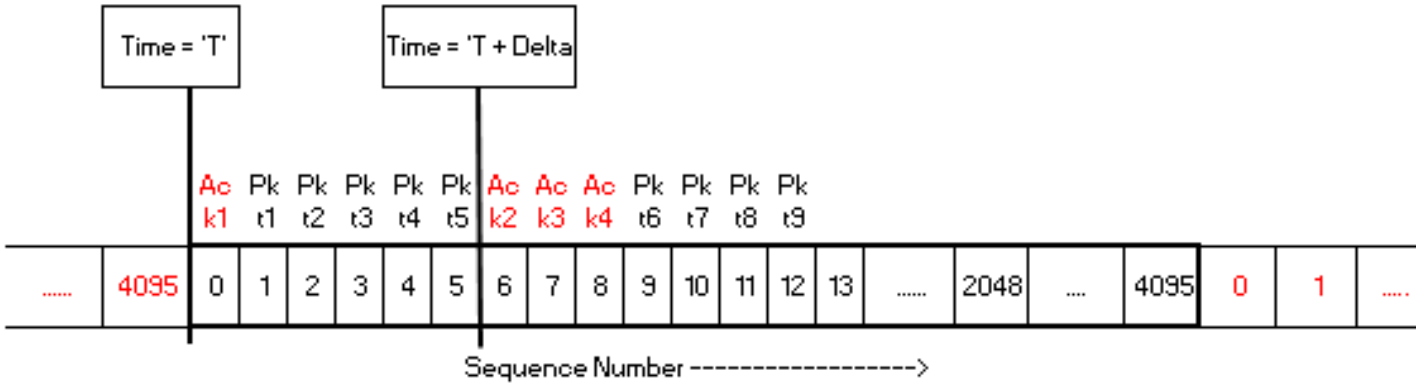
Proposed Scheme-1b : Allocate SN to UL packet in advance

- This scheme does not allocate SN to UL packets, i.e. TCP non-ACK packets related to UL traffic or TCP ACK packets acknowledging the DL traffic, as they arrive in the UL packet queue from the application.

- The scheme computes a number of UL packets which can be transmitted in a time period and allocates SNs in the PDCP and or RLC SN space only to these UL packets even if there are more UL packets in the queue.

- The computation is based on one or more factors or a combination of UE's computation capability, UL grant rate, signal conditions, network load, carrier aggregation behavior and other similar factors.

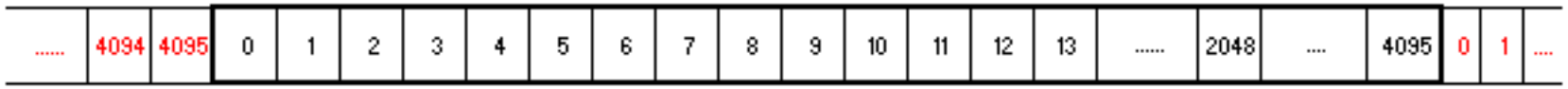
Proposed Scheme-1b : Allocate SN to UL packet in advance



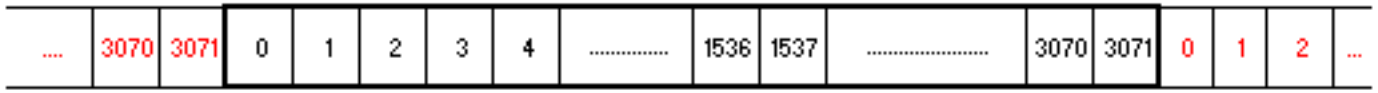
Propose Scheme-2: Divide SN space

- The scheme-2 betters earlier proposed schemes and requires minimal 3GPP standard change.
- The method divides the PDCP/RLC SN space into two parts, where
  - allocation of SNs from the first part is done for only TCP non-ACK packets and
  - from the second part for only TCP ACK packets.
- The respective part of SN space follows in sequence delivery procedure.
- While forming the UL MAC TB, UE first prioritizes packet from the SN space belonging to TCP ACK and then from the other part. Thus TCP ACK packet gets transmitted earlier.
- This scheme dedicates a segment of SN space itself specifically for TCP ACKs, therefore, it performs comparatively better than both scheme-1a and 1b.
- In this scheme allocation for SN to TCP ACK packet is not limited by its arrival time in UL packet queue; it gets immediate SN allocation and prioritization during transmission.

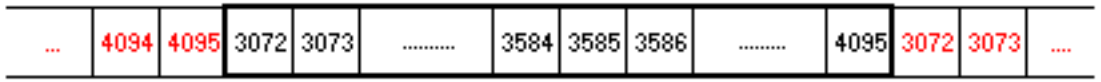
Propose Scheme-2: Divide SN space



Sequence Number ---------->



SN PART-1 :: Sequence Number ---------->



SN PART-2 :: Sequence Numbar ---------->

NOTE 1 - SN PART -1 is wrapping to initial sequence number 0 after reaching MAX_SN 3071. UL SN SPACE PART-1 SIZE = 3072

NOTE 2 - SN PART -2 is wrapping to initial sequence number 3072. UL SN SPACE PART-2 SIZE = 1024

Simulation Environment

- We have modeled all proposed schemes mathematically and simulated on a standard setup for several scenarios of simultaneous UL and DL.

- Scheme-1a was modeled in accordance with the reserving hole-SNs in static way at every Nth packet; where N was fixed to different value ranging from 3 to 10 depending on the ratio of UL to DL TP.

- Scheme-1b is modeled by limiting the advance UL PDU formation by next K TTI; where K was fixed to 4ms

- For scheme-2, both network and UE side PDCP behavior was modeled, where PDCP SN is broken into 2 parts: PDCP SN part 1 size limited to 3072 and SN part 2 as 1024. ACK packet was scheduled prior of data packet while scheduling UL resources.

Simulation Results

Respective Gains with the proposed schemes for DL/UL TP scenarios

Scenario	DL (Mbps)	UL (Mbps)	Scheme-1a	Scheme-1b	Scheme-2
scenario 1	15	45	23%	25%	26%
scenario 2	15	30	17%	20%	20%
scenario 3	30	30	12%	16%	18%
scenario 4	30	15	5%	8%	10%

Conclusions

- This paper discusses two novel solutions to prioritize TCP ACK which addresses low TP in simultaneous UL/DL traffic scenarios.
- Through mathematical modelling and simulation on standard LTE setup, it shows effective decrease in downloading time by 5 ~ 25% for two variants of the first scheme.
- The computation cycle consumed to figure out the TCP packet type is very minimal and hence not causing any overhead in the UE; suitable for low-end UEs.
- Both the solutions can be extended to prioritize other TCP select packets too like Domain Name Server (DNS) query, SYN or SYN ACK packet etc. to achieve faster TCP SYNC and DNS response from network

References

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