**Slide 1**

Performance Analysis of
Periodic Cellular-IoT Communication
with Immediate Release of Radio Resources

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Slide 2

Background 1/2

- IoT communications
  - Massive number of devices with different communication characteristics
    - Event-driven, periodic, timer-based, …
- Problems when accommodated in mobile cellular networks
  - Data and control planes may experience congestion
  - Congestion at E-UTRAN (radio access networks) and EPC (core networks)

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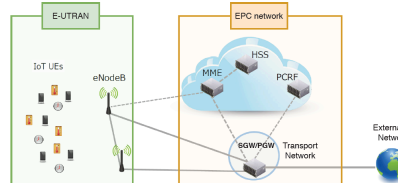
Background 2/2

- NB-IoT
  - Subset of LTE standard with different configurations
  - Lower speed, wider coverage, lower power consumption
- Immediate release of radio resources after data transmission
  - Considered in 3GPP
  - Effective for IoT devices with periodic communications
  - In standard LTE, radio resources is kept hold for 10 [sec]
- Few existing studies on evaluating the performance of cellular-based, periodic IoT communications with immediate release of radio resources

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Purpose

- Performance analysis of cellular-based IoT communication
  - End-to-end: random access procedure, radio resource allocation, bearer establishment, and data transmission
  - Dimensional Markov chain model and queueing theory are exploited
- Evaluate the capacity of mobile cellular networks for IoT communications
  - Comparison of LTE and NB-IoT
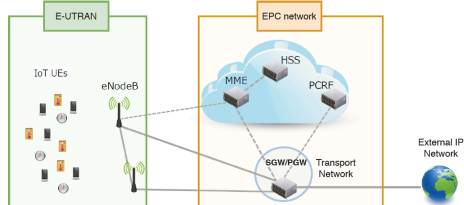 - Effect of immediate release of radio resources
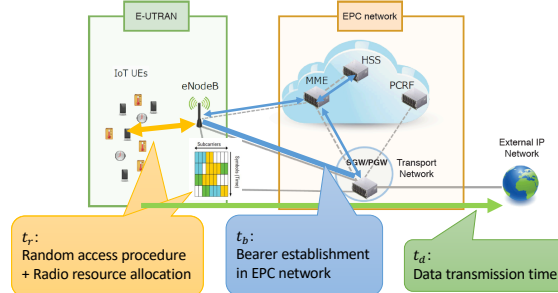
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Performance analysis

$$t_{service} = t_r + t_b + t_d$$

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Slide 6
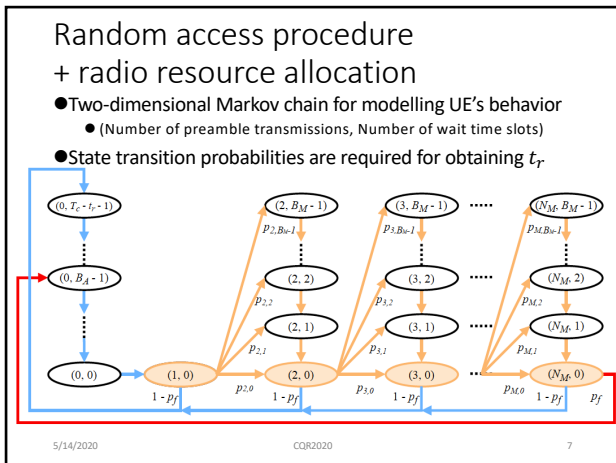
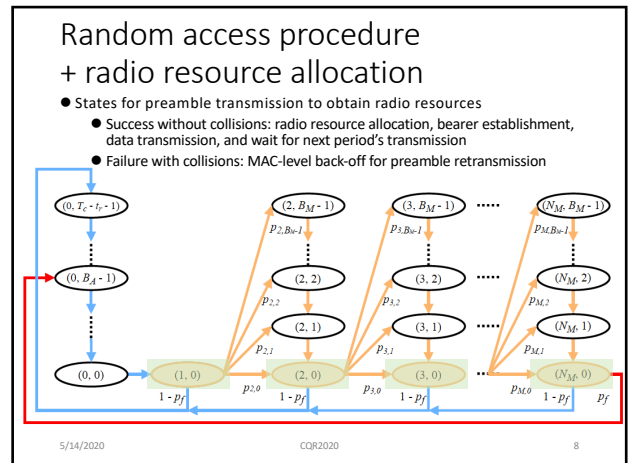## Performance analysis

$$t_{service} = t_r + t_b + t_d$$

t_r:
Random access procedure
+ Radio resource allocation

t_b:
Bearer establishment
in EPC network

t_d:
Data transmission time

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Random access procedure
+ radio resource allocation
- Two-dimensional Markov chain for modelling UE's behavior
  - (Number of preamble transmissions, Number of wait time slots)
- State transition probabilities are required for obtaining t_r

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Slide 8

Random access procedure
+ radio resource allocation
- States for preamble transmission to obtain radio resources
  - Success without collisions: radio resource allocation, bearer establishment, data transmission, and wait for next period's transmission
  - Failure with collisions: MAC-level back-off for preamble retransmission

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Random access procedure
+ radio resource allocation
- States and transitions for periodic transmission

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Slide 10

Random access procedure
+ radio resource allocation
- States and transitions for MAC-level back-offs to retransmit preambles

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Slide 11

Random access procedure
+ radio resource allocation
- State transition for application-level back-off
  - After N_M times of preamble retransmissions failure

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Calculating state transition probabilities

Collision probability in preamble transmission:
$$p_c = 1 - \left(\frac{P-1}{P}\right)^{(N_U-1)p_t}$$

Probability at which UE is at one of the states for preamble transmission:
$$p_t = \frac{2(1-(p_f)^{N_M})}{2(T_c - t_r + 1)(1 - p_f) + (B_M + 1)p_f(1 - (p_f)^{N_M-1}))}$$

Failure probability of preamble transmission and radio resource allocation
$$p_f = 1 - (1 - p_c)(1 - p_r)$$

Failure probability of radio resource allocation:
$$p_r = \frac{\frac{(\lambda\tau)^K}{K!}}{\sum_{i=0}^{K}\frac{(\lambda\tau)^i}{i!}}$$

N_U: Number of UEs
T_c: Communication cycle
N_M: Maximum number of preamble retransmissions
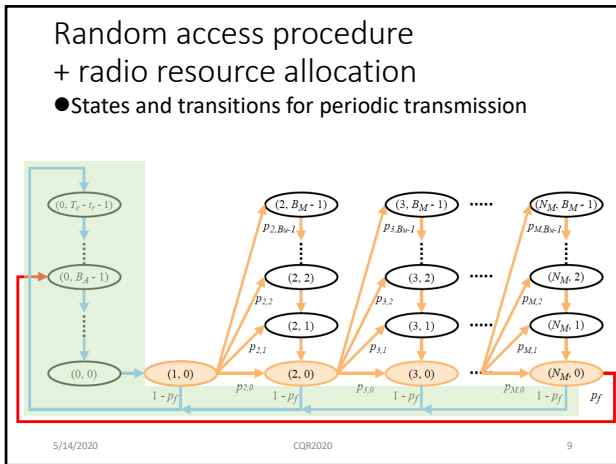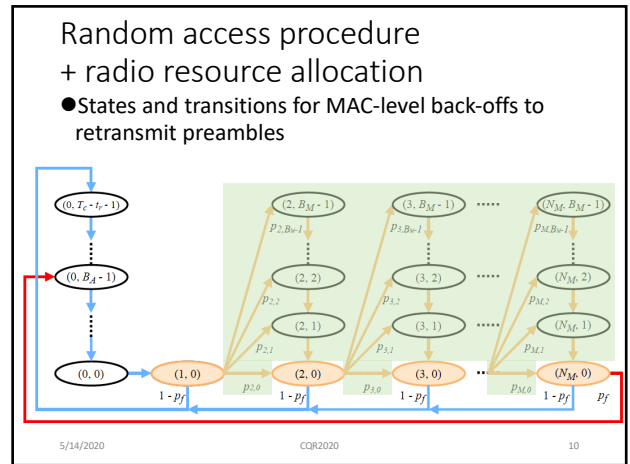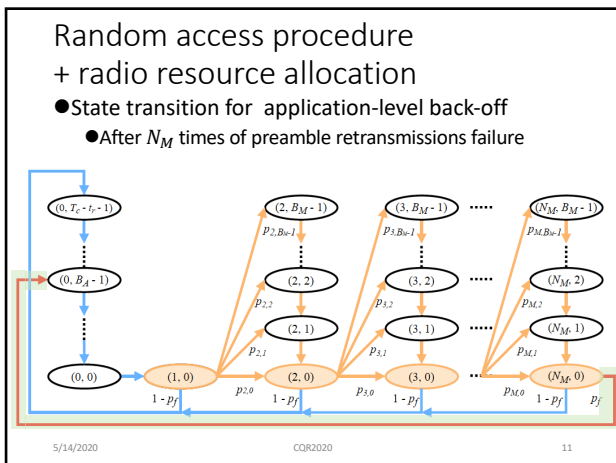B_M: Maximum length of MAC-level back-off
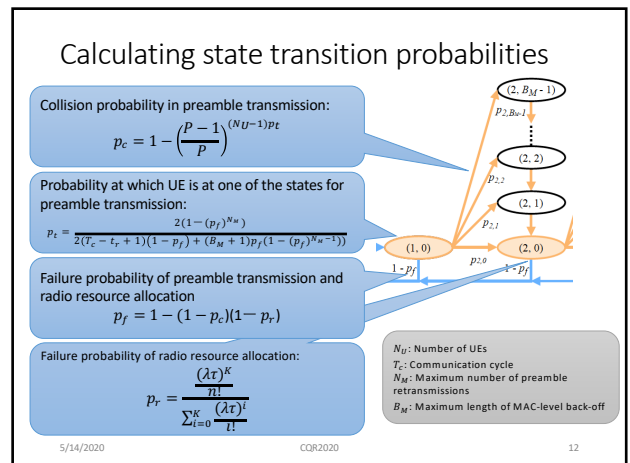

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Radio Resource Allocation

- M/D/K/K queuing model is exploited
  - Poisson arrival process of UEs that successfully transmit their preambles
  - Radio resource is kept allocated until an inactivity timer expires
  - The number of radio resource blocks (RBs) allocated to a UE is fixed
- Failure probability for radio resource allocation p_r

  - $p_r = \dfrac{\frac{(\lambda\tau)^K}{K!}}{\sum_{l=0}^{K}\frac{(\lambda\tau)^l}{l!}}$

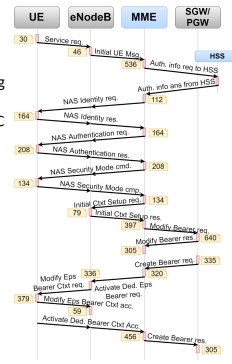| Variable in M/D/K/K queuing model	Related Parameter in evaluation
λ: Arrival rate	The number of of UEs, UE's communication frequency, and success probability of preamble transmission
τ: Serving Time	Inactivity timer (10 [sec] for standard LTE, $t_{service}$ [sec] for immediate release of radio resources)
K: The number of servers	Total number of RBs and the number of RBs allocated to each UE

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Bearer establishment procedure

- Bearer establishment time (t_b)
  - Execution time required for the signaling procedure
- Sum of propagation delays and processing times of signaling messages
  - Propagation delay: Distance between EPC nodes/eNB/UE
  - Processing time: M/G/1/PS model

$$E[R] = \frac{\rho^r}{1-\rho}\frac{E[S^2]}{2E[S]} + \frac{1-\rho^r}{1-\rho}E[S]$$

ρ: System utilization, calculated by number of UEs, UE's communication frequency, and success prob. of preamble transmission and radio resource allocation
S: Workload distribution, determined by signaling flow and source code for EPC software
r: Number of parallel processors

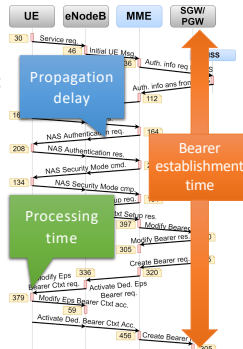5/14/2020   CQR2020   14

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Bearer establishment procedure

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Data transmission time

- Calculated from the bandwidth of links between UE and SPGW, and the transmitted data size

$$t_d = \sum_{N_1, N_2 \in \mathbb{V}} \left(n_{d_{N_1,N_2}} \cdot t_{d_{N_1,N_2}} \right)$$

$$t_{d_{N_1,N_2}} = \frac{C}{W_{N_1,N_2}}$$

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Numerical evaluation

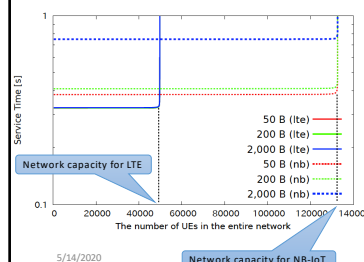- Evaluation metrics: Service time
- Compare LTE and NB-IoT

Parameters	LTE	NB-IoT
Radio bandwidth	20 [MHz]	20 [MHz] (in-band mode)
Number of preambles	54	48
Wireless link speed	22.9 [Mbps]	0.106 [Mbps]
Allocated RBs for each UE	6	2/3

- Immediate release of radio resources
  - Radio resources are kept allocated until the inactivity timer expires
  - Inactivity timer: 10 [s] for traditional LTE, equal to $t_{service}$ with immediate release of radio resources

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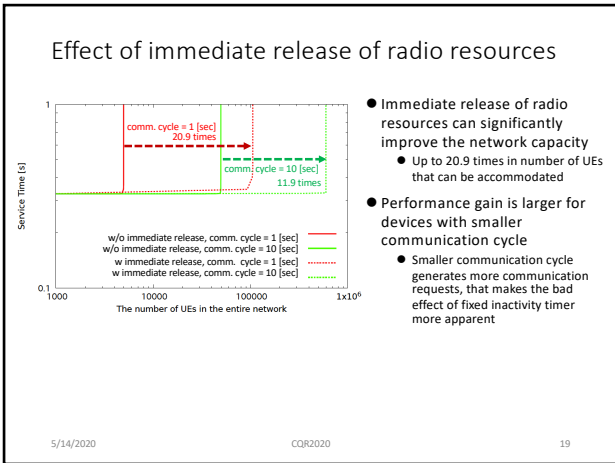## Comparison of LTE and NB-IoT

- Service time increases sharply with a certain number of accommodated UEs
  - Defined as network capacity

- NB-IoT shows larger network capacity, while larger service time than LTE
  - Difference in allocated RBs for each UE
- Transmission data size does not affect the service time in LTE
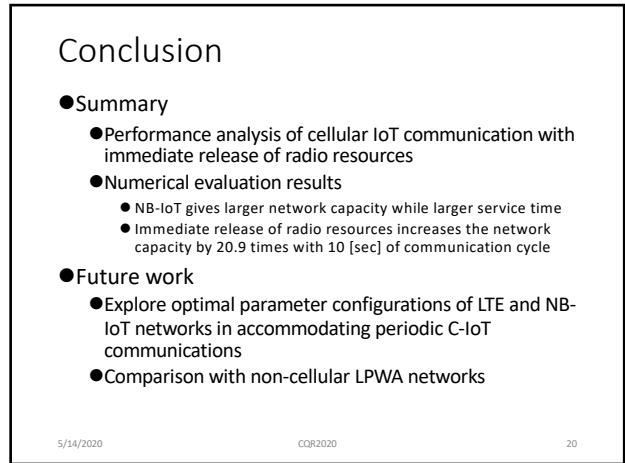 - Large bandwidth is allocated to each UE

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Effect of immediate release of radio resources

- Immediate release of radio resources can significantly improve the network capacity
  - Up to 20.9 times in number of UEs that can be accommodated
- Performance gain is larger for devices with smaller communication cycle
  - Smaller communication cycle generates more communication requests, that makes the bad effect of fixed inactivity timer more apparent

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Conclusion

- Summary
  - Performance analysis of cellular IoT communication with immediate release of radio resources
  - Numerical evaluation results
    - NB-IoT gives larger network capacity while larger service time
    - Immediate release of radio resources increases the network capacity by 20.9 times with 10 [sec] of communication cycle
- Future work
  - Explore optimal parameter configurations of LTE and NB-IoT networks in accommodating periodic C-IoT communications
  - Comparison with non-cellular LPWA networks

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