Distributed Computer Systems Lab
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TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Seminar Seminar: Distributed Computer Systems SS23

On the Reliability of LTE Random Access: Performance Bounds for Machine-to-Machine Burst Resolution Time

Speaker
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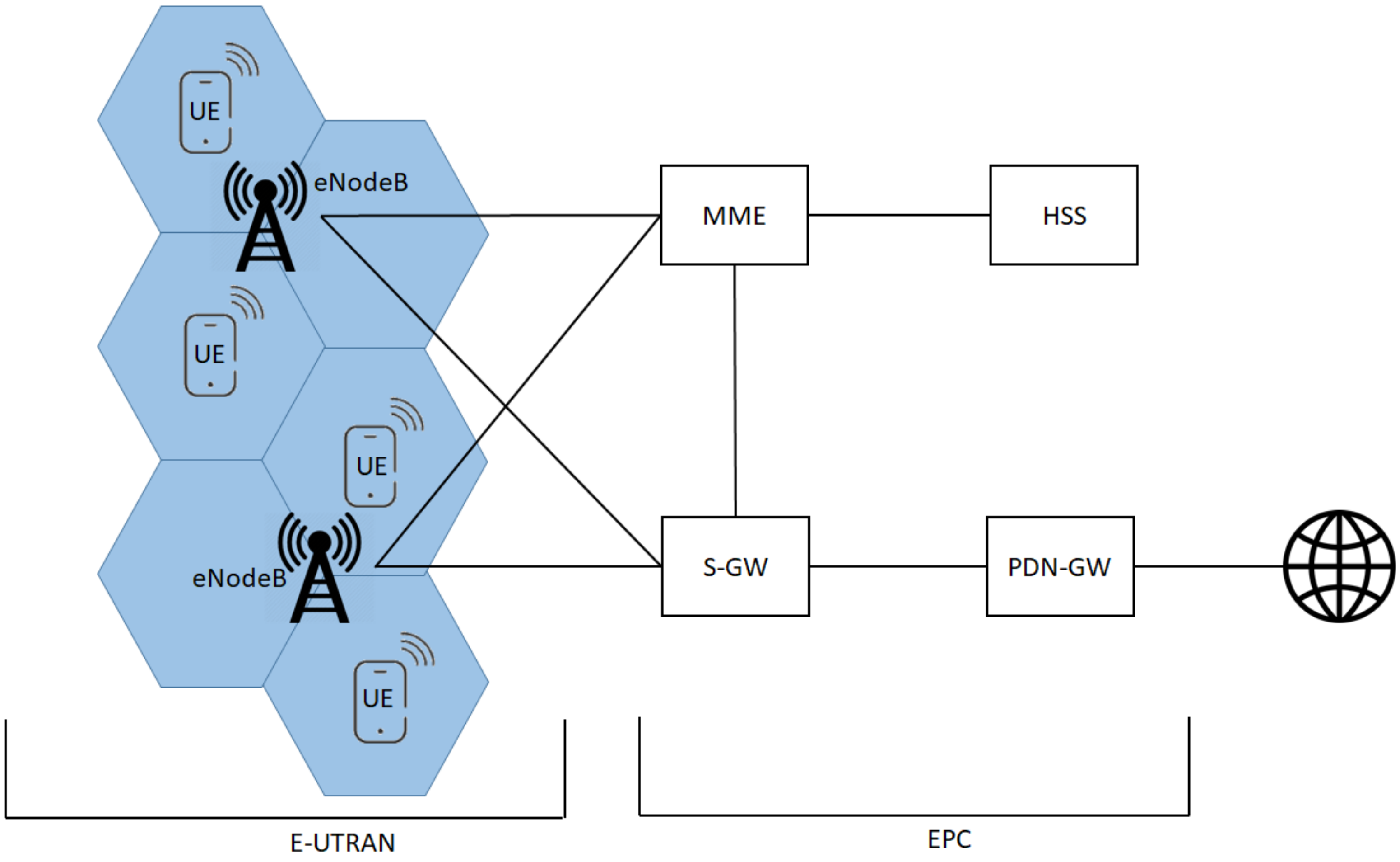
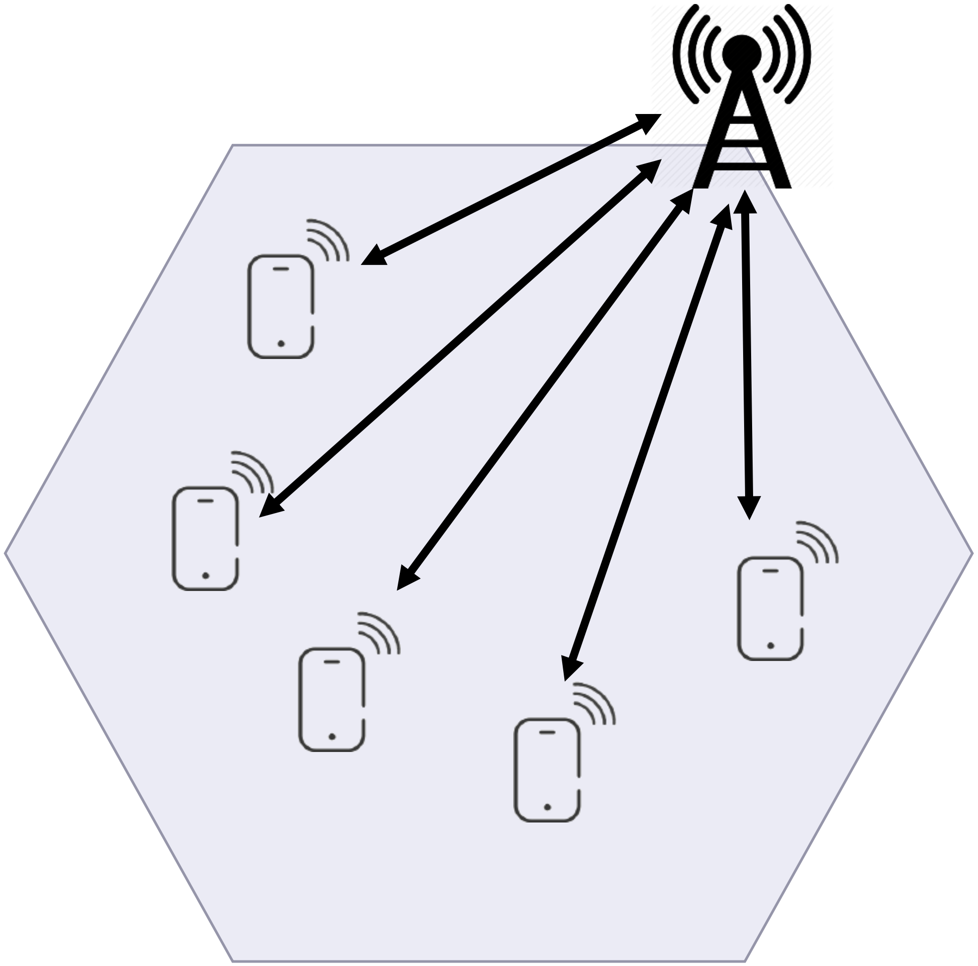
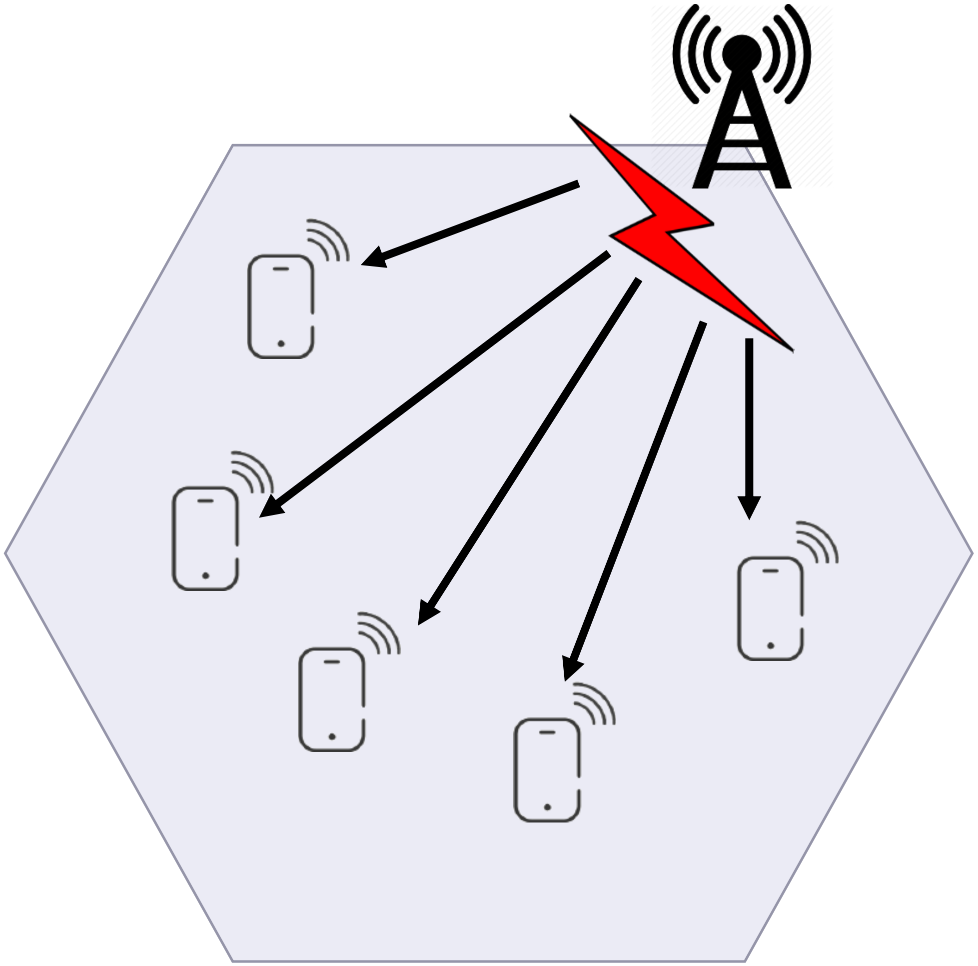
LTE Networks



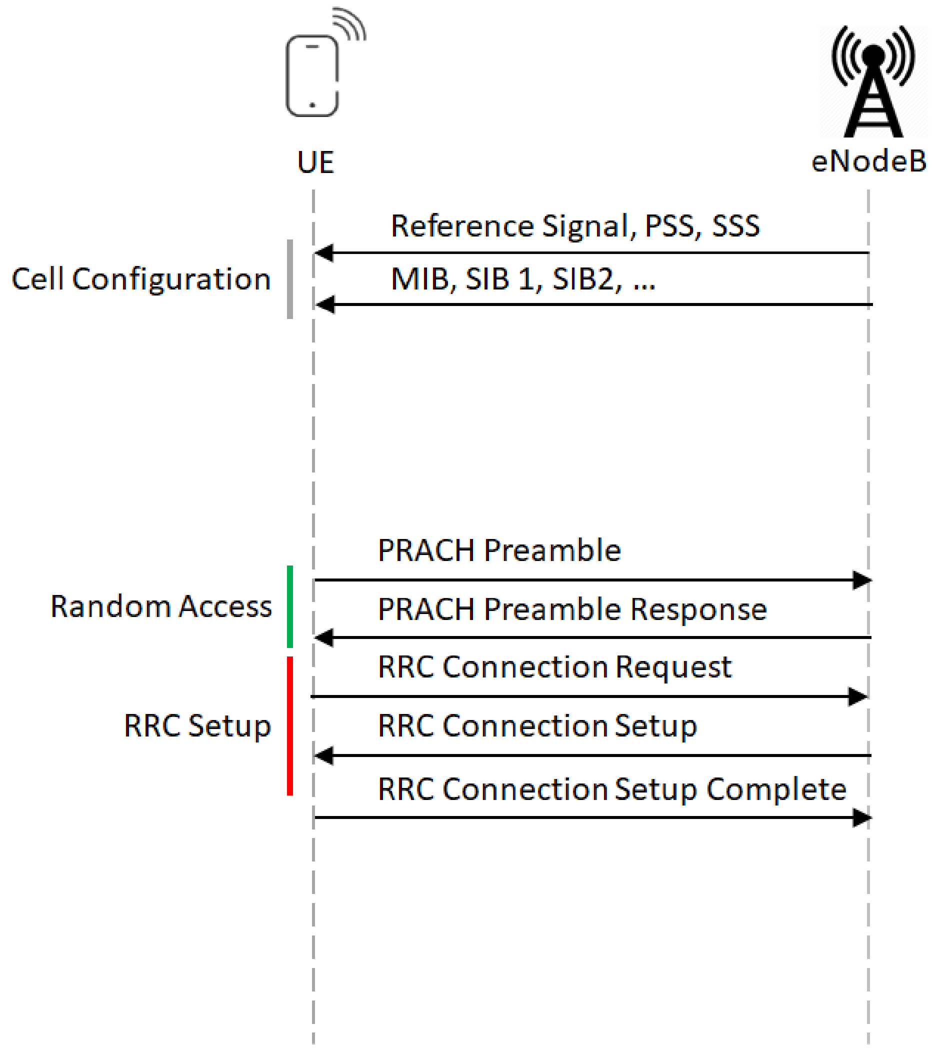
RACH Procedure as Bottleneck



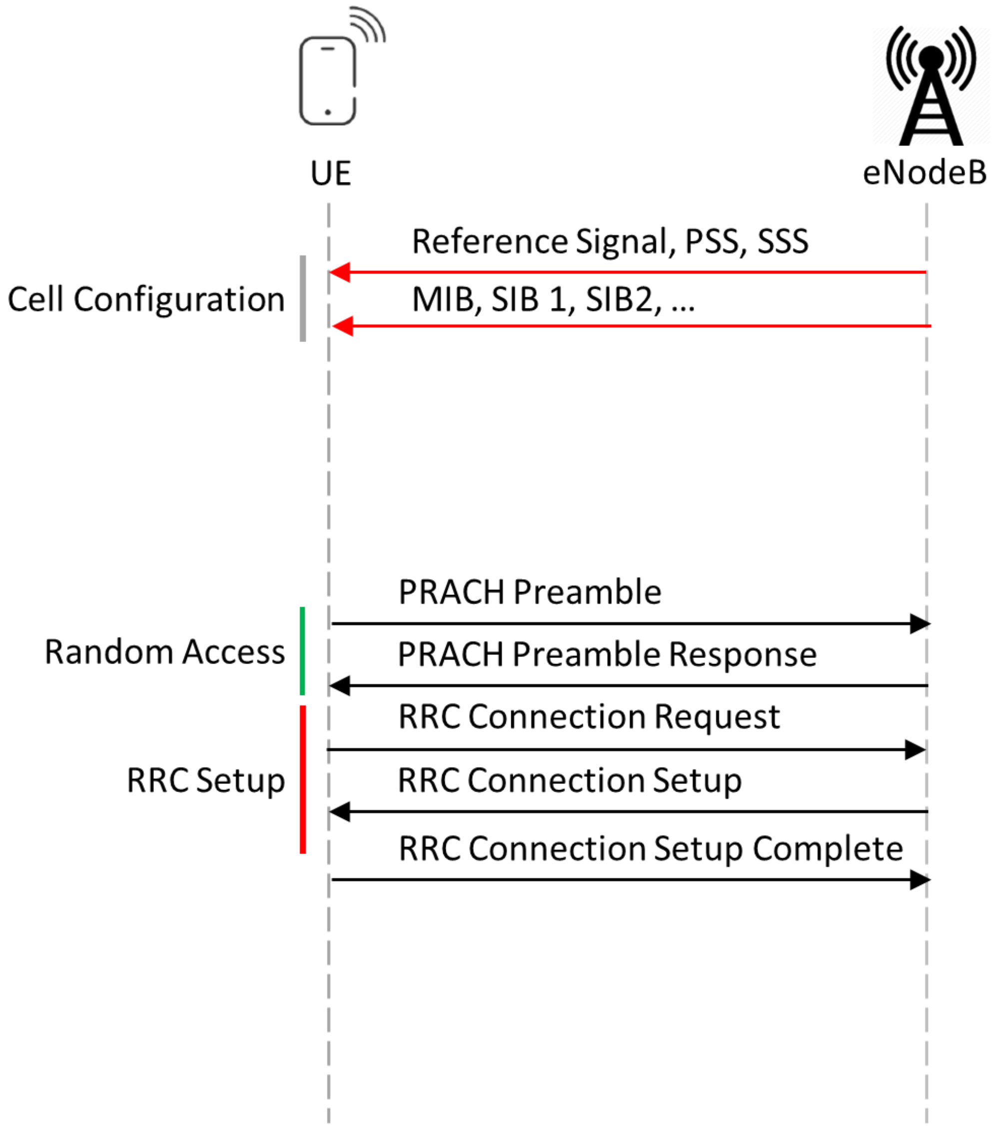
RACH Procedure as Bottleneck



RACH Procedure in Detail



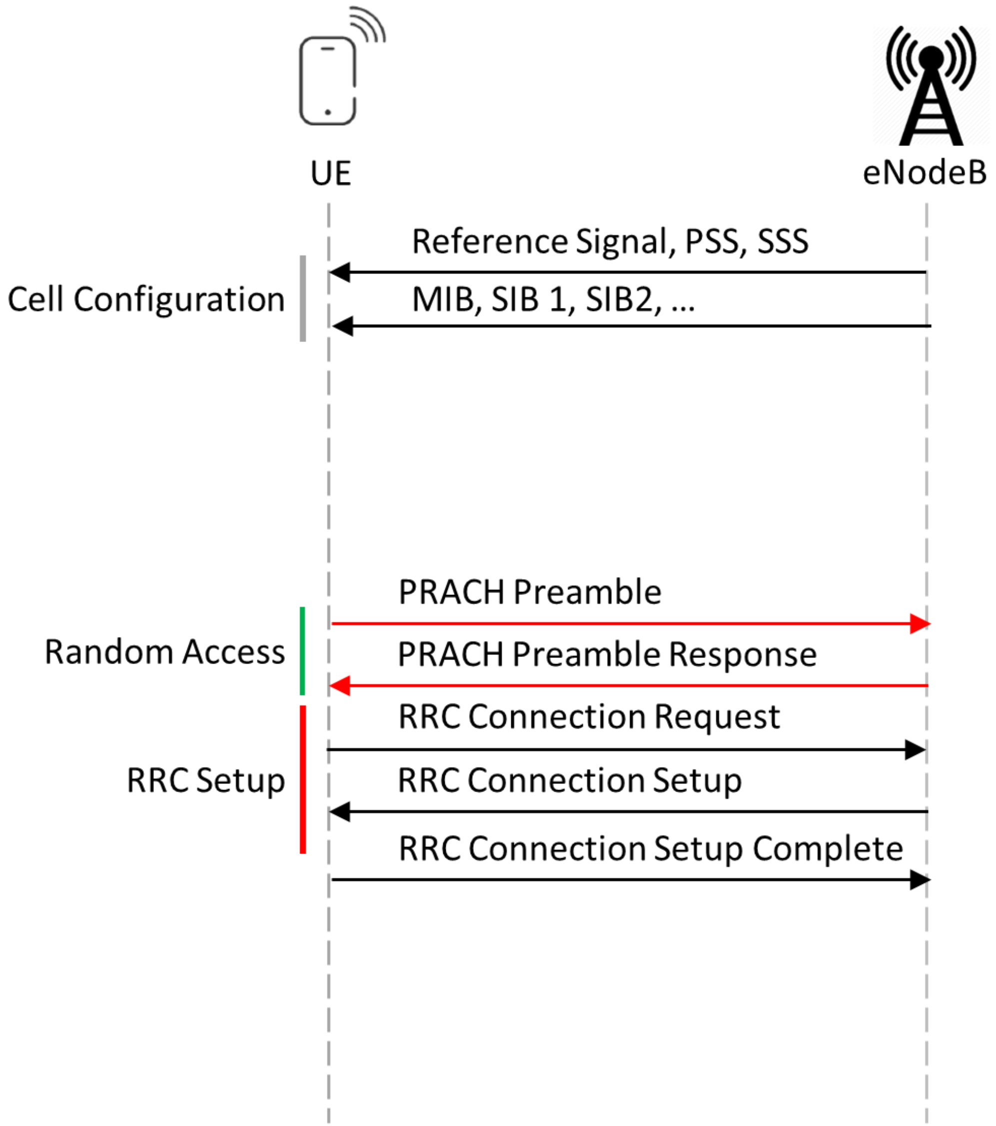
RACH Procedure



Objectives of UE:

- Synchronization
- Sending signal power
- Cell Configuration

RACH Procedure



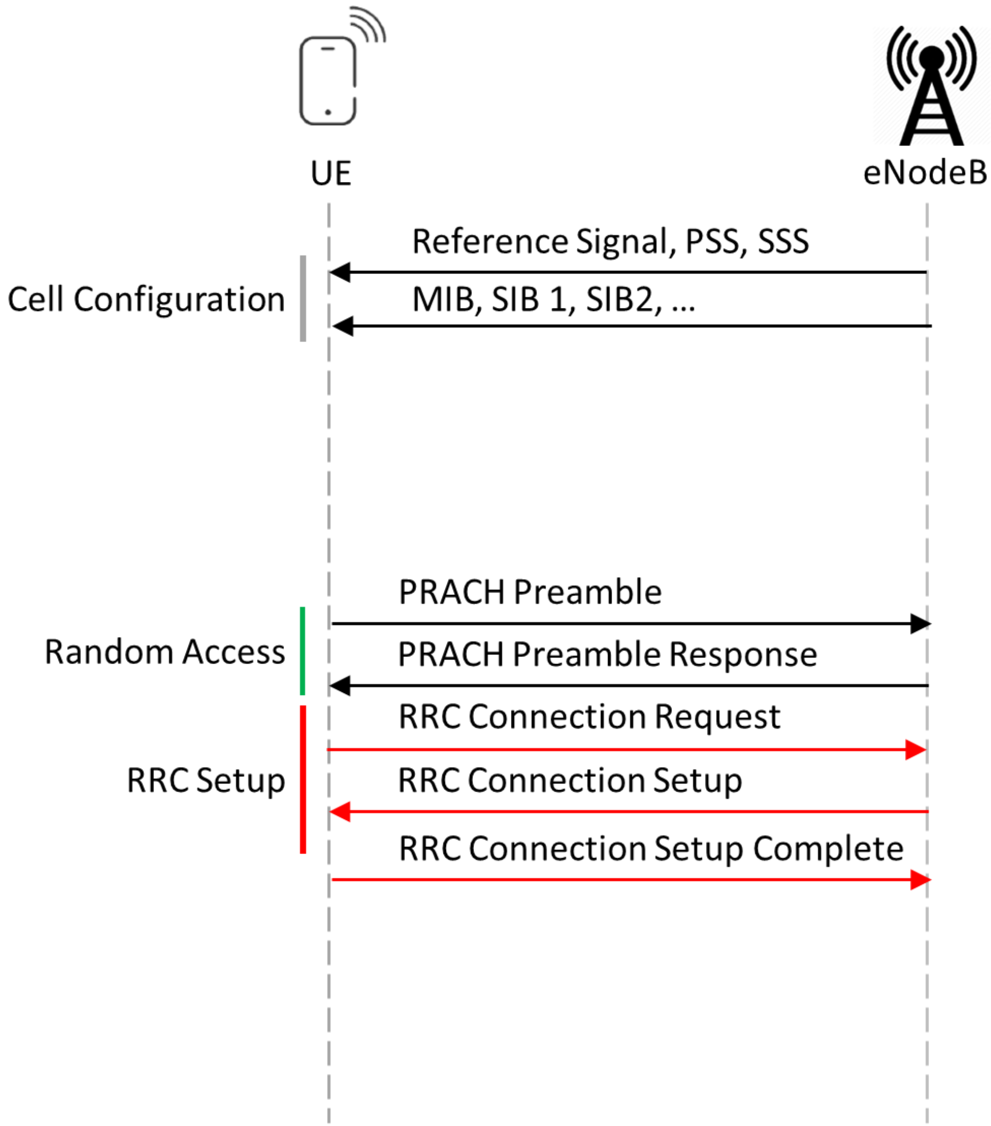
UE:

- Send one of M Preambles on PRACH

eNodeB:

- Reply containing UL Grant on PRACH

RACH Procedure

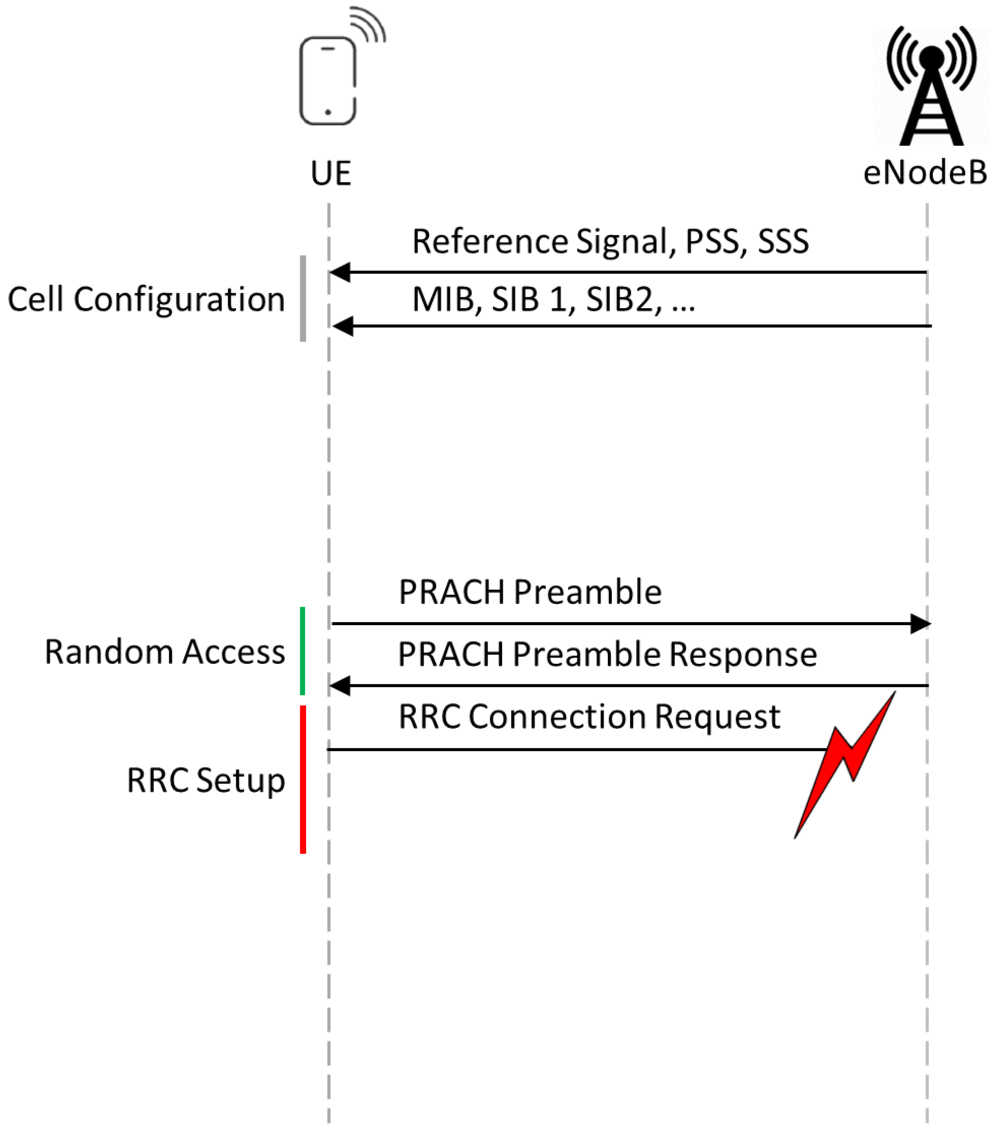


Objective:

- Exchange UE specific Data
- Uses granted Resources

→ UE is signed up at eNodeB

RACH Procedure



Preamble:
- Contains no UE specific Data

→ Will collide constructivly

Preamble Response:
- Assigns Grant to multiple Ues

Connection Request:
- Contains UE specific Data

Will collide destructivly

Access Class Barring

< LTE SIB2 >

```
sib2
   ac-BarringInfo
      ...1 .... ac-BarringForEmergency: True
      ac-BarringForMO-Signalling
         ac-BarringFactor: p00 (0)
         ac-BarringTime: s4 (0)
         ac-BarringForSpecialAC: 10000 (bitmap)
      ac-BarringForMO-Data
         ac-BarringFactor: p00 (0)
         ac-BarringTime: s4 (0)
         ac-BarringForSpecialAC: 00000 (bitmap)
   ....
   ssac-BarringForMMTEL-Voice-r9
      ac-BarringFactor: p00 (0)
      ac-BarringTime: s4 (0)
      ac-BarringForSpecialAC: 00000 (bitmap)
   ssac-BarringForMMTEL-Video-r9
      ac-BarringFactor: p00 (0)
      ac-BarringTime: s4 (0)
      ac-BarringForSpecialAC: 00000 (bitmap)
```

Different Access Class Barring Policies:

1. No Access Class Barring
2. Static Access Class Barring
   → Set p staticly
   $$p = x$$
3. Optimal Dynamic Access Class Barring
   → Change p every Frame
   $$p = min\left\{1, \frac{M}{B(i)}\right\}$$
4. Estimated Dynamic Access Class Barring
   Observe # of idle preambles
   Complex Algorithm based on Bayesian Algorithm

Analysis Quality of Service

$$qos = (b^{\epsilon}, t, \epsilon)$$

- b^{ϵ} is the allowed Backlog
- t is the time by which we demand that $B(t) \leq b^{\epsilon}$
- ϵ the allowed probability of violating the backlog condition

Analysis System Characteristics

$$sc = (N, M, a_i, acb)$$

- M is the number of Preambles
- N is the number of UEs arriving at t_0
- a_i is the number of UEs arriving at t_i
- acb is the Access Barring Policy
- $B(i)$ is the Backlog at t_i

Recursive Analysis

$$s_{i,m} = \begin{cases} 1 \quad if\ chosen\ by\ 1\ UE \\ 0 \qquad\qquad\qquad else \end{cases}$$

$$B(i+1) \\ = \max\{0, B(i) + a_i - s\_i\}$$

- Enables recursive calculations of Backlog
- Access Barring Policies can be applied every step
- Slow

Probabilistic Analysis

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***Abstract*—Random Access Channel (RACH) has been identified as one of the major bottlenecks for accommodating massive number of Machine-to-Machine (M2M) devices in LTE networks, especially in the case of bursty arrivals of connection requests. As a consequence, the burst resolution problem has sparked a large number of works analyzing and optimizing the expected performance of RACH. In this paper, we go beyond the study of performance in expectation by investigating the probabilistic performance limits of RACH with access class barring. We model RACH as a queuing system, and apply stochastic network calculus to derive probabilistic performance bounds for burst resolution time, i.e., the time it takes to connect a burst of M2M devices to the base station. We illustrate the accuracy of the proposed methodology and its potential applications in performance assessment and system dimensioning.**

I. Introduction

One of the main goals for the evolution from current wireless systems to 5G is to support massive Machine-to-Machine (M2M) communications. This could enable a number of promising applications, such as large scale sensor and actuator networks, smart grid monitoring, and many more [1]. Main challenges for enabling massive M2M are: improving scalability, enhancing energy efficiency and decreasing the

developed [2], for instance, by means of back-off or barring, e.g., pseudo-Bayesian broadcast [6], or tree resolution algorithms [5]. For LTE, standardized mechanism to deal with burst arrivals is Access Class Barring (ACB) [3]: re-shaping the burst by broadcasting a RACH access probability for all UEs.

In the state-of-the-art, the performance of ACB and its derivatives [7], [8] has been extensively studied *in the expectation*, i.e., with respect to the *average* burst resolution time and resulting RACH efficiency [8]–[12]. In [9] and the follow-up work [10], the authors devised an analytical framework to assess the expected performance of the standardized ACB and Extended Access Class Barring (EAB) procedures, respectively. Jian *et al.* [12] have proposed another iterative approach to the ACB analysis, and Koseoglu [11] derived the lower bound on the average random access delay.

However, for many applications on the border between massive M2M and ultra reliable M2M [13], e.g., in-cabin communication in an aircraft or large-scale industrial automation [14], assessing the average performance is insufficient. For instance, if all the sensors in a factory need to re-connect after an emergency shutdown within a certain time limit [14]. In that case, *reliability guarantees for the RACH performance*

- Model Backlog Probability distribution with Moment Generating Functions

$$\mathbb{P}\left[s_i = k | b_i' = x\right] = \binom{x}{k}\binom{M}{k}\frac{k!}{M^x} \times$$
$$\times \sum_{j=1}^{j_{\max}} (-1)^j \binom{M-k}{j}\binom{x-k}{j} j!\,(M-k-j)^{x-k-j}$$

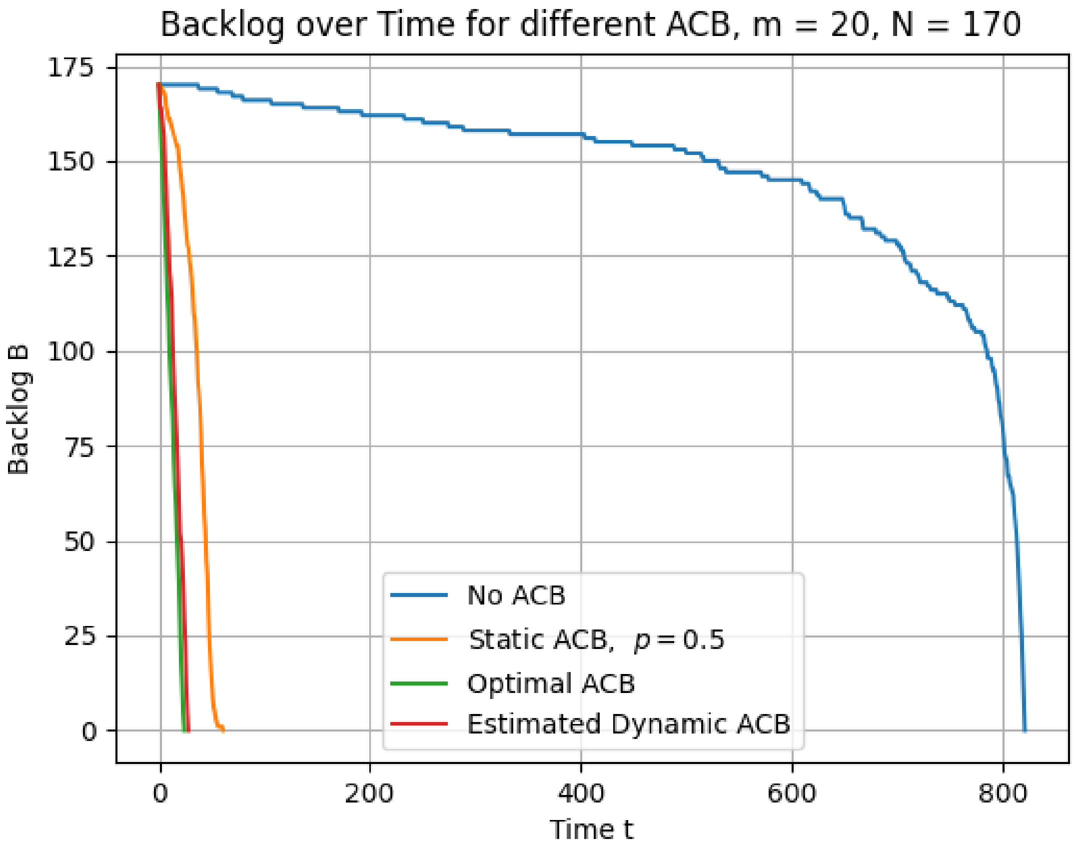
- Fast Analysis
- Compute satisfiable QoS Requirements
- Dimension LTE Networks
- Compare different Access Barring Policies

Simulation

Algorithm 2 Simulation Loop

Initialize N and $p_0 = 1/M$
while $B > b^\epsilon$ or $t_c < t$ **do**
    $t_c += 1$
    draw B samples from a binomial distribution to get nr admitted ues a
    draw a random integer samples from a uniform distribution $[0..M]$
    count the number of occurences of each preamble
    $s_i =$ number of preambles chosen exactly once
    $B -= s_i$
    update p for dynamic ACB policies
end while
if $B > b^\epsilon$ **then**
    return success
else
    return failure
end if

Simulation Result: Backlog over Time



Simulation Results