Estimating the Number of Contending Users at the Random Access Channel in LTE-A networks to Design Congestion Control Schemes for Providing Machine-Type Communications

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Abstract

Machine-type communication (MTC) is considered an integral part of the so-called Internet of Things. MTC provides ubiquitous connectivity among devices (UEs) without human intervention. Using cellular networks to provide MTC connectivity presents numerous advantages such as coverage, roaming support, interoperability, well developed charging, quality of service and security solutions, among others. However, a large number of UEs, that may need to communicate over a short period, can cause severe congestion which hugely impacts the radio access and core networks of the cellular system. The Physical Random Access Channel (PRACH) is used to signal a connection request when a UE desires to access the cellular network. To increase the success rate of a massive number of access attempts to the evolved node B (eNB) is necessary to design congestion control schemes. For that, the key piece of information is the total number of UEs competing in the PRACH. To estimate this number at the eNB, we find the joint probability distribution function (PDF) of the number of successful and collided preambles within a random access slot. Then, we design a maximum likelihood estimator using this PDF. Numerical results showcase the accuracy and usefulness of the proposed method even if the number of access attempts is significant.

LTE-A contention-based random access procedure

Introduction

- In LTE-A, the random access (RA) procedure must be performed by any UE to access the cellular network (send/receive information).

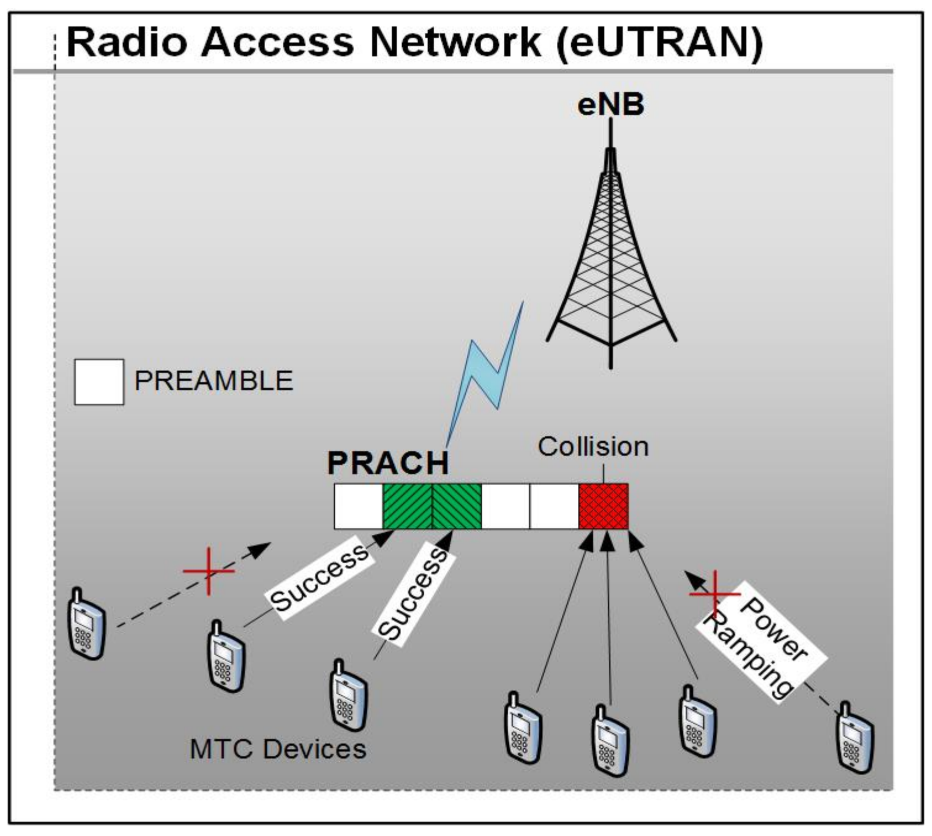

Figure 1. Preamble transmission

- The Physical Random Access Channel (PRACH) is used to signal a connection request.
- RA attempts are done in predefined time/frequency resources called RA slots.
- If a UE tries to access to a RA slot, it must select randomly a preamble (signature) for the very first message of RA procedure.
- The RA procedure can be seen as a multichannel ALOHA [1], where congestion control is studied by estimating the number of UEs that send preambles to the eNB [2].

Four-message handshake

- In **Msg1**, a UE transmits a randomly chosen preamble from the preamble pool during one of the available RA slots. A preamble will be detected at the eNB if it has not been chosen by more than one UE in the same RA slot.
- Then, the eNB sends a random access response (RAR) message, **Msg2**, including a fixed number of uplink grants (one for each detected preamble). Msg2 is used to assign time-frequency resources to the devices for the transmission of Msg3.
- Next, the UEs that received an uplink grant send their connection request message, **Msg3**, during the resources specified by the eNB.
- Finally, the eNB responds to each Msg3 transmission with a contention resolution message, **Msg4**. Refer to [3,4,5,6] for further details.

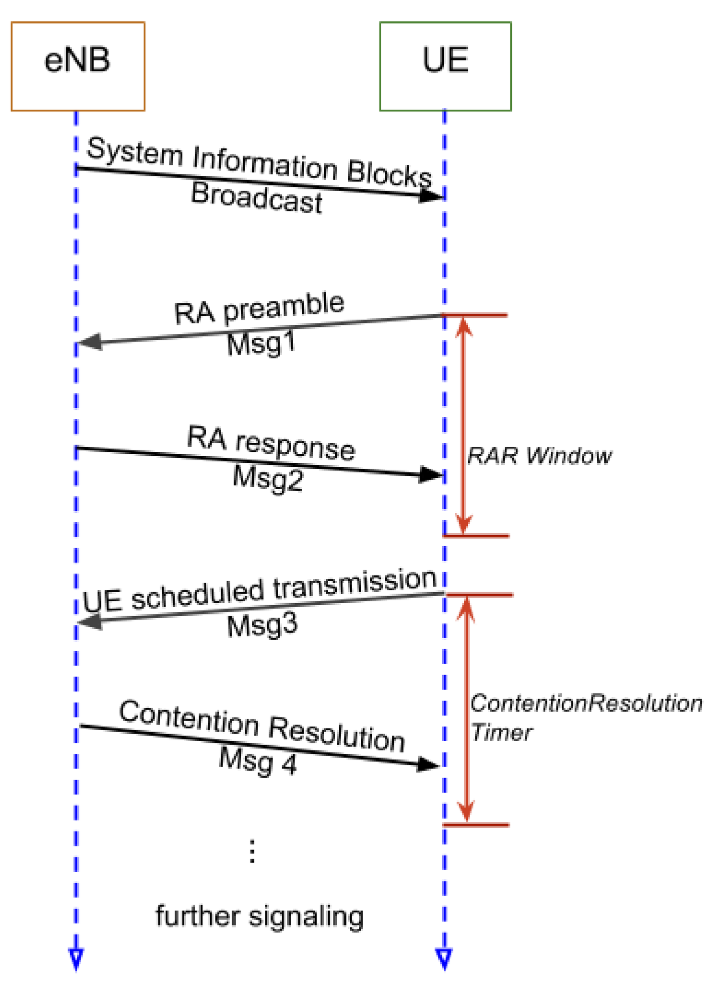

Figure 2. Contention-based Random Access Procedure

Joint Probability Distribution Function (PDF) of successful, collided and not-used preambles

Let us focus on a single RA slot with r preambles, and denote by

N: the r.v. representing the number of UEs which randomly select their transmission preamble among the r preambles available in the RA slot.
S: the r.v. representing the number of preambles successfully transmitted.
C: the r.v. representing the number of collided preambles.
U: the r.v. representing the number of not-used preambles.

Let $P_n(s,c) = Prob(S = s, C = c, U = r - s - c | N = n)$ and $P_n(s) = Prob(S = s | N = n) = \sum_c P_n(s,c)$. Next we present a numerically efficient iterative procedure to compute $P_n(s,c)$.

Estimating the number of contending UEs at eNB

Recursive approach for computing $P_n(s,c)$ as the number of UEs in the system, *n*, increases

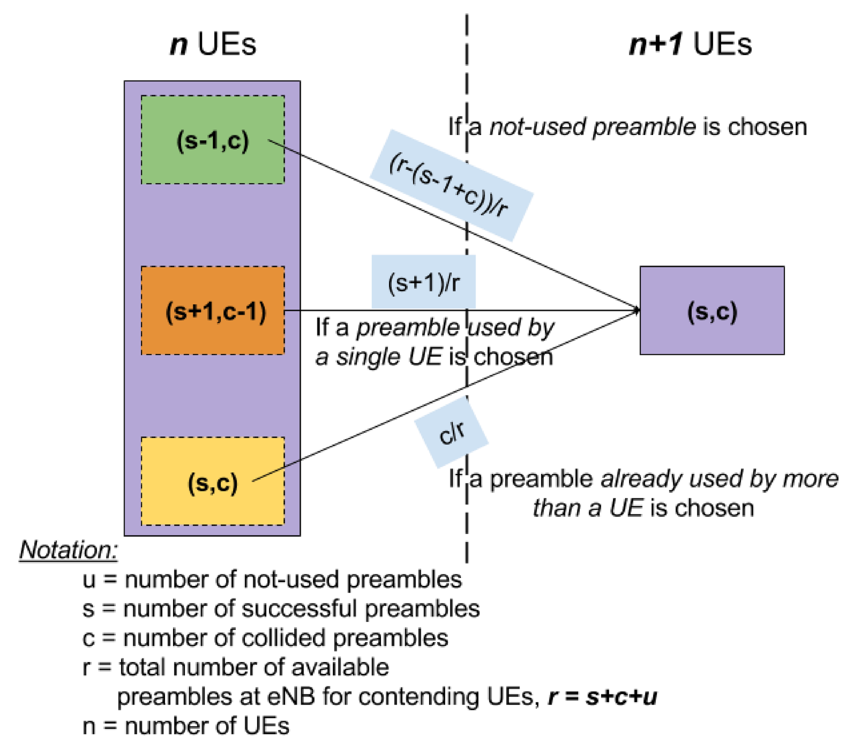

Figure 3. Diagram of the recursive approach

$$\boldsymbol{P_{n+1}(s,c)} = \frac{r-(s-1+c)}{r} P_n(s-1,c) + \frac{(s+1)}{r} P_n(s+1,c-1) + \frac{c}{r} P_n(s,c)$$

- Computationally tractable operation. Can be solved offline numerically for a great number of UEs (n).
- A look-up table is obtained. This table is computed once and can be used throughout the operation of the system.

Maximum Likelihood Estimator (MLE) from $P_n(s,c)$

$$\hat{N} = \underset{n}{argmax}\, P_n(s,c)$$

There is a unique corresponding MLE for each observed s and c. The complexity is reduced during its online operation.

Results

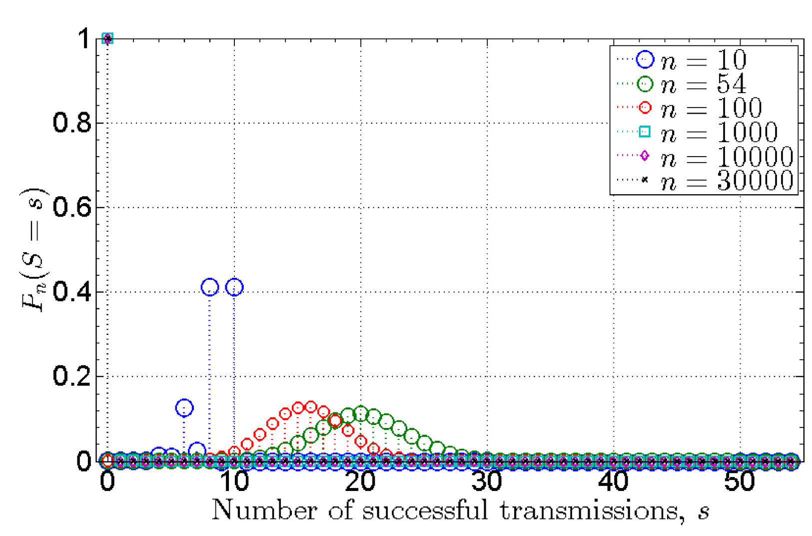

Figure 4. Distribution of the number of successful transmissions, $P_n(s)$, in a given RA slot, r=54

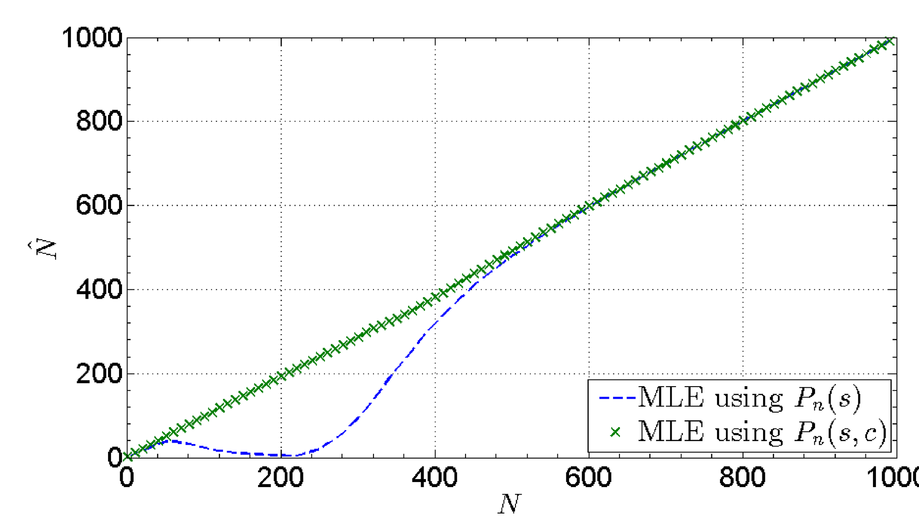

Figure 5. Estimation of the number of contending UEs at the eNB by MLE

Conclusions and future work

- We presented an analytical approach to estimate the number of contending users in one random access slot for an LTE-A network.
- Numerical results showed that the proposed method can accurately estimate the number of contending MTC devices even for large network loads.
- This approach can further be extended to design static or dynamic congestion control schemes for alleviating the radio access network overload and optimize the parameter setting of these overload control schemes.

References

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