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Gateway-assisted two-stage radio access for machine type communication in LTE-Advanced network☆

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A B S T R A C T

In Long Term Evolution-Advanced (LTE-A) network, Machine Type Communication (MTC) provides random access-based communication for automation applications. One of the most critical issues in MTC is the emergence of large number of MTC devices which may send requests to the base station simultaneously, and incur severe collision at the base station. When collision occurs, the data delivery fails, and the message delay accumulates.

In this paper, we propose a gateway-assisted two-stage (GATS) radio access scheme to alleviate collision for delay-tolerant MTC applications. In GATS, MTC devices are divided into several groups, where random access in each group (as the first stage) is controlled by a device called MTC gateway. Collision of random access to the base station (as the second stage) is then effectively alleviated. Then we propose analytical model and simulation model to investigate the performance of GATS in terms of utilization of random access slots, access success probability and average message delay. Simulation results show that, by sacrificing a little message delay, GATS scheme significantly improves access success probability. Besides, when the group number increases, the delay becomes smaller.

1. Introduction

Long Term Evolution-Advanced (LTE-Advanced or simply LTE-A) is one of the major fourth generation mobile communication technologies proposed by 3rd Generation Partnership Project (3GPP). In LTE-A network, Machine Type Communication (MTC) enables many automation applications without or with little human intervention, such as smart meter, e-care and home automation [1]. MTC devices gain access to random access channels (RACHs) from a base station (called eNodeB) for establishing data transmission. A collision occurs when more than one device attempts to connect to a channel at the same time. MTC network is supposed to involve a quite large number of end devices, such that access congestion in RACH becomes one of the most critical issues in LTE-A network [2].

A simplified LTE-A network architecture for MTC is shown in Fig. 1. In this figure, LTE-A network is divided into two parts: radio access network (RAN; Fig. 1(a)) and core network (CN; Fig. 1(b)). In the RAN, MTC devices (Fig. 1(1)) communicate with eNodeBs (eNBs; Fig. 1(2)) directly or indirectly through an MTC capillary network (Fig. 1(c)) [3]. MTC capillary network, similar to existing Wireless Personal Area Networks (WPANs), provides connectivity between MTC devices and MTC gateways (Fig. 1(4)). WPAN technologies, such as Zigbee and Bluetooth standardized by IEEE 802.15 working group, are widely used in MTC capillary network. Compared to other WPAN technologies, Zigbee has lower power consumption and wider transmission range such that Zigbee becomes one of the most popular technologies used in MTC capillary network. In the CN, Mobility Management Entity (MME; Fig. 1(5)) is a control plane entity for mobility and bearer management. The data from MTC devices are delivered to an MTC server (Fig. 1(6)) through Serving Gateway (S-GW; Fig. 1(7)) and Packet Data Network Gateway (P-GW; Fig. 1(8)). Besides, MTC devices can also communicate with each other directly. When an MTC device attempts to synchronize with an MTC server, the MTC device performs a random access procedure in physical random access channel (PRACH) [4]. PRACH is a physical channel while RACH is the corresponding logical channel. In LTE-A network, each cell typically has 64 available random access preamble sequences while 5MHz spectrum is allocated. All random access preambles are different Zadoff-Chu sequences administered by eNBs [5]. Random access procedure in LTE-A is classified into two categories:

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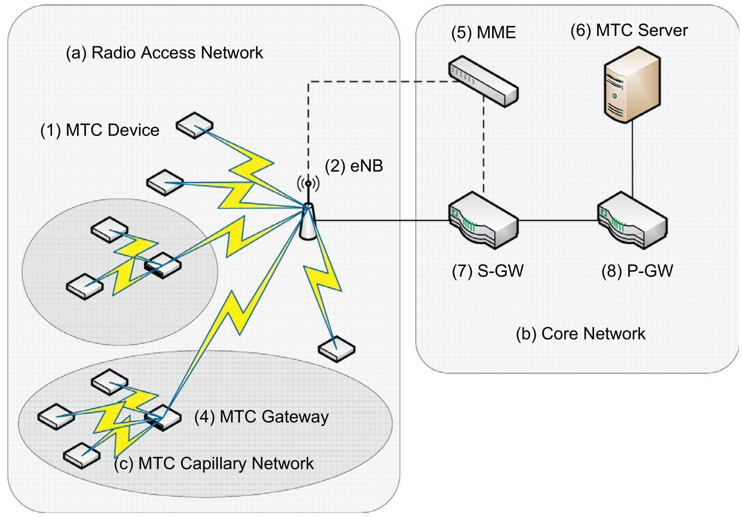

Fig. 1. LTE-A MTC network architecture.

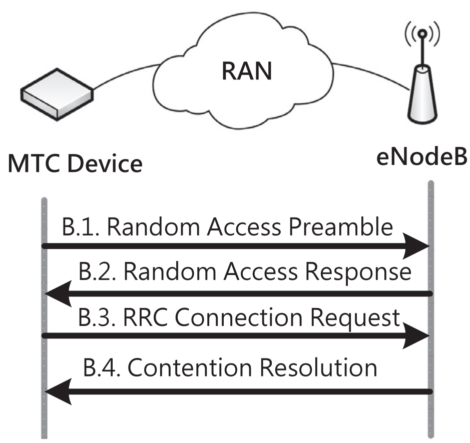

Fig. 2. Message flow of basic LTE-A random access.

- *Contention-based*: Random access preamble is randomly chosen by MTC devices. Collision occurs if more than one MTC device chooses the same preamble at the same time.
- *Contention-free*: The eNB assigns dedicate random access preambles to MTC devices. There is no collision problem in random access procedure with dedicate preambles.

Contention-free random access procedure is mainly used in handover. In most cases, contention-based random access procedure is more feasible for massive MTC devices with limited resource. Massive access from large number of MTC devices may cause severe random access network congestion. Furthermore, when a severe congestion occurs, the access delay for MTC devices may be too long and unacceptable.

Fig. 2 illustrates the message flow of basic LTE-A random access between MTC device and eNB with the following steps [6]:

Step B.1. The MTC device randomly chooses a sequence from available RACH preambles. Then the MTC device transmits a Random Access Preamble message in PRACH to the eNB.

Step B.2. When the eNB detects the preamble sequence (i.e. no collision), the eNB transmits a Random Access Response (RAR) message to the MTC device. The RAR message contains a temporary cell radio network temporary identity (TC-RNTI) and uplink grant. The TC-RNTI is used later at **Step B.3**. If the transmission is successful then TC-RNTI is promoted to cell radio network temporary identity (C-RNTI). Uplink grant is a resource block assignment used by MTC device for sending RRC connection request in uplink shared channel (UL-SCH).

Step B.3. The MTC device sends an RRC Connection Request message to the eNB in UL-SCH. The RRC Connection Request message includes the device's identity (i.e. IMSI and TMSI) which are used to get C-RNTI.

Step B.4. The eNB sends a Contention Resolution message to the MTC device. The Contention Resolution message contains a C-RNTI used for further communication. If the eNB receives two or more RRC connection requests with the same TC-RNTI, the eNB does not send the Contention Resolution message to those MTC devices. The condition is considered as collision and the random access procedure is postponed by a backoff time.

This paper proposes a two-stage radio access scheme to alleviate random access congestion for group-based MTC. Before communicating with eNB directly, an MTC device needs to get the permission from its group leader. In this way, the collisions at eNB are transferred to the group.

Below is the organization of this paper. Section 2 describes existing solutions for MTC random access congestion. Then we propose the Gateway-Assisted Two-Stage Access scheme to alleviate congestion in Section 3. In Section 4, we describe analytic models to study the performance of MTC congestion control. The proposed analytic models are validated against simulation experiments. Based on the simulation experiments, Section 5 investigates the performance of MTC congestion control.

2. Related works

This section introduces existing RAN and CN congestion control techniques proposed in 3GPP TR 37.868 [7] and further improvement in literature.

Four solutions are introduced in 3GPP TR 37.868 for MTC congestion control:

- *Solution* 1. *Access Class Barring (ACB)*: Initially, MTC devices are divided into several access classes. When the random access procedure is initiated, the eNodeB broadcasts an ACB parameter (including an access probability and barring duration) for each access class. When an MTC device wants to transmit data, the MTC device generates a random number within the range