Self-Adaptive Persistent Contention Scheme for Scheduling Based Machine Type Communications in LTE System

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***Abstract*—Machine Type Communication (MTC), which allows different devices to communicate without the needs of human to machine interactions, has been developed in recent years. However, MTC possibly resulting in an unexpectedly high collision rate is different from contemporary mobile communication service when it involves a very large number of communication terminals with little traffic requirement. As a solution, we propose a self-adaptive persistent contention scheme to schedule MTC devices in a periodical reporting manner. Moreover, the proposed scheme not only solves the congestion problem but also achieve significant uplink bandwidth utilization improvement as well as backward compatibility for the existing wireless communication framework. Simulation results demonstrate that the proposed scheme significantly promotes the transmission efficiency.**

***Index Terms*—Contention scheme, Long Term Evolution (LTE), Machine Type Communication (MTC), OPNET Simulator.**

I. Introduction

Mobile wireless communication is widely used in human communications such as voice call, messaging, and web browsing. With the increasing of related applications, most people are getting used to the ubiquitous network. However, these kinds of services and technologies are matured and new kinds of services and technologies are requested. Services of mobile communications have been extended from Human to Human (H2H) to Machine to Machine (M2M). Generally, the operators consider M2M as the potential of being the fastest booming market in the worldwide communication networks, because millions machine devices need to use cellular technologies in telematics, security, automatic meter reading, payment, vending machines and so on. The characteristics of broad bandwidth and low latency in the 4G network are proper to be used in various transmission services. As defined in 3GPP specifications [1] [2] [3] [4], M2M is also called as Machine Type Communication (MTC). MTC is a form of data communication which involves one or more entities that do not need human interaction. There are several unique characteristics in MTC applications, such as extensive application market, little traffic per terminal, low cost, low power consumption and a potentially huge number of terminal equipments. All MTC devices may influence the usage of radio resources of the existing mobile communication systems.

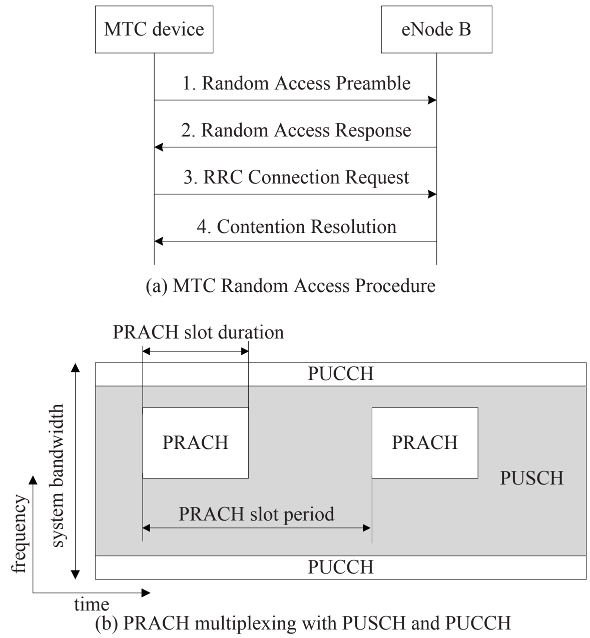
According to the framework of the Long Term Evolution (LTE) system of 3GPP [5] [6] [7], a user equipment (UE) [8] and the serving evolved Node B (eNB) must perform at least the following steps when it desires to upload data to the serving eNB: 1) the UE selects one of sixty-four preambles for transmitting an uplink transmission request to the eNB, 2) the eNB replies a relevant message to the UE in response to the preamble, 3) the UE transmits an uplink bandwidth request to the eNB in response to the relevant message, and 4) the eNB makes a schedule to allow the UE to upload data. In LTE system architecture, unsynchronized UE has to contend with other UEs for uplink bandwidth before data transmission. Therefore, the LTE random access channel (RACH) [9] [10] [11] [12] plays a significant role as an interface between non-synchronized UEs and the orthogonal transmission scheme of the LTE uplink radio access.

However, documents [13] [14] [15] reveal the contention schemes of wireless communication system designed according to the needs and/or behaviors of H2H, they could not handle the amount of traffic requests from MTC devices in a short term period. With the needs of MTC devices increase, the number of MTC devices becomes several orders of magnitude greater than H2H devices. The radio network is challenged by the new type of users. In other words, a large number of MTC devices are expected to be deployed in a specific area, thus the network has to face increased load as well as possible surges of MTC traffic. The legacy contention schemes may not be affordable when there are a huge number of MTC devices trying to access the network simultaneously.

To curb the severe congestion problem and reduce the impact on QoS of existing H2H devices, this paper proposes a novel contention scheme, namely self-adaptive persistent contention (SPC) scheme, which take the advantages of the existing contention schemes. To solve the mentioned issue, the proposed scheme not only eases the congestion impact on H2H devices due to MTC devices but also minimizes the uplink bandwidth utilization of MTC devices without violating the existing mobile communication systems.

The remainder of this paper is organized as follows. Section II describes the MTC random access procedure in LTE. Section III introduces the envisioned radio access network (RAN) improvements for M2M devices and the SPC scheme in this paper. Sections IV shows the system parameters and simulation results. Finally, Section V completes this paper with conclusions and future works.

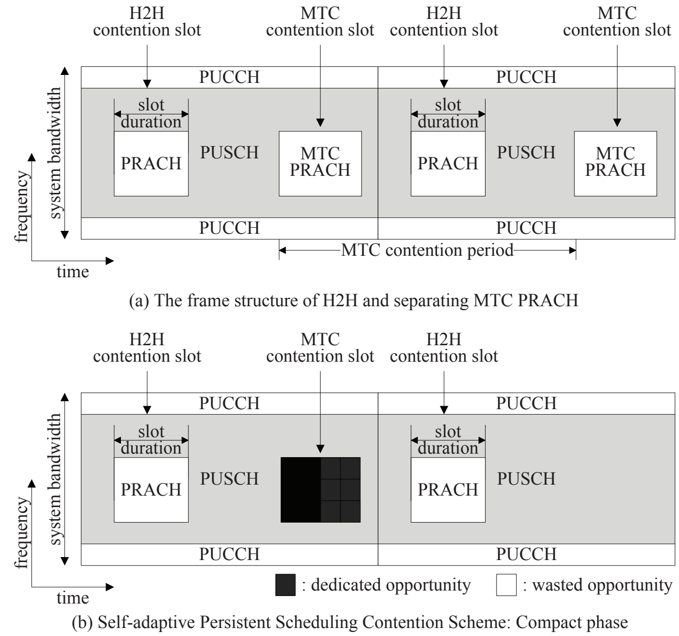
978-1-4673-0937-0/12/$31.00



(a) MTC Random Access Procedure

(b) PRACH multiplexing with PUSCH and PUCCH

Fig. 1. Contention-based random access procedure and frame structure of PRACH.



(a) The frame structure of H2H and separating MTC PRACH

(b) Self-adaptive Persistent Scheduling Contention Scheme: Compact phase

Fig. 2. The frame structure of H2H and self-adaptive persistent scheduling MTC.

II. MTC Random Access Procedure

The congestion of MTC network usually happens in radio network, signaling network and core network because of mass concurrent signaling and data transmissions. The radio network congestion resulted from the amount of MTC devices and the random access procedure, which is applied for every device before accessing network. A large number of MTC devices are deployed in a specific area for certain purpose. Mass concurrent data transmission takes place in some MTC applications. For example, all the sensors transmit the monitoring data simultaneously when a train passes through the bridge. If MTC devices contend for uplink bandwidth with H2H devices simultaneously, the huge amount of MTC devices would decrease the contention success probability of H2H devices. In the worst case, MTC devices may paralyze the RACH. Even though the system has uplink resource, there is no device to access the radio network due to serious congestion. Radio network congestion may cause intolerable delay, packet loss or even service unavailability. MTC to guarantee network availability and help network to meet performance requirements is worthwhile to be investigated.

First of all, we introduce the MTC random access procedure and basic frame structure in the MTC operation. As portrayed in Fig. 1(a), the MTC random access procedure are composed of four steps: 1) transmitting Random Access Preamble, 2) receiving Random Access Response (RAR), 3) transmitting Radio Resource Control (RRC) Connection Request [16], and 4) receiving Contention Resolution. In the first step, every MTC device selects one signature from the $64 - N$ available Physical Random Access Channel (PRACH) contention-based signatures, where N represents the number of signatures reserved by the eNB for contention-free RACH, where PRACH is time-multiplexed and frequency-multiplexed with Physical Uplink Shared Channel (PUSCH) and Physical Uplink Control Channel (PUCCH) as illustrated in Fig. 1(b). The PRACH time-frequency resources are semi-statically allocated within the PUSCH region and repeated periodically. In the second step, MTC device expects to receive the RAR within RAR window. If it fails to receive the RAR within the RAR window, the RAR reception is considered not successful. The MTC device shall increase preamble transmission counter by one, and select a random backoff time according to a uniform distribution between zero and the backoff parameter value. It would delay the subsequent Random Access transmission by the backoff time and try a new random access attempt. In the third step, MTC devices collide on the uplink resource when they transmit RRC connection request which is the first uplink transmission generated by RRC layer including tracking area update and scheduling request. Collided MTC devices have to restart random access procedure after reaching the maximum number of Hybrid Automatic Retransmission request (HARQ) retransmission. If RRC connection request of one MTC device is successfully decoded, the state of the other MTC devices still stays unresolved status. In the last step, a MTC device knows whether the Contention Resolution is for itself according to the MTC identity and transmit the HARQ feedback to the eNB. Other MTC devices observing the same downlink resources find out whether the Contention Resolution is destined to them. They stop HARQ feedback and quit the current random access procedure and perform another one when the random access procedure is failed.

III. Self-adaptive Persistent Contention (SPC) Scheme

The concept of self-adaptive persistent contention (SPC) scheme is based on Extended Access Barring (EAB), Separate RACH Resources, Dynamic Allocation of RACH Resources, MTC Specific Backoff, and Pull Based Scheme [17] [18]. MTC devices, which use the MTC PRACH for periodical data transmissions, encounter a fierce contention at the first time. The communication between the eNB and the MTC devices by means of SPC scheme is adjusted into a perfect contention patent in every following transmission in the realizable frame structures. The proposed scheme is divided into two phases, 1) the contention phase and 2) the compact phase as shown in Fig. 2(a) and (b) respectively. In the contention phase, the purpose is to decrease the collision probability, re-attempt count and access delay. In the compact phase, the purpose is to minimize the physical resource utilization for MTC and reduce the signaling overhead from Core Network (CN) to the front-end. In the following sections, two phases are discussed in detail.

A. Contention Phase

When MTC devices turn on the power, they perform cell selection and listen to the system broadcast to acquire the essential information about the MTC PRACH and EAB factors. All of the MTC devices are separated into ten groups according to the extended access classes, the advantage of separating MTC devices through EAB is to avoid the simultaneous contention and increase the access success probability. The MTC devices perform the random access procedure in each group and set up a period to observe the successful contention count. The counter increases when MTC device listens to a contention resolution and record the successful order until random access succeed. Once a collision occurs, the devices perform specific random backoff to re-attempt. After contention succeed, the MTC device would memorize the successful information, which contains the preamble sequence, successful contention frame, and successful contention order, to reuse in the next access period. The algorithm of contention phase is shown as below, where t_id, f_id, p_id, T_ID, F_ID, P_ID, and k denotes the time index of the chosen subframe of RACH resource, the specified RACH resource within that subframe, the index of the chosen random access preamble, the time index of the chosen subframe of RACH resource in the first successful contention, the specified RACH resource within that subframe in the first successful contention, the index of the chosen random access preamble in the first successful contention, and the k-th contention attempt among devices, respectively. N_p is the number of available preambles in a RACH. BI is the backoff indicator. M is the multiple PRACHs per subframe.

B. Compact Phase

When the eNB is aware that the competition of MTC devices is stable, it reduces the MTC PRACH to the minimum access requirement through broadcast messages. If the MTC

Algorithm 1: Contention phase

Input: Given a new coming MTC device (t_id, f_id, p_id, k).
Output: The first successful contention information (T_ID, F_ID, P_ID, k).

$t\_id = 0$; $f\_id = 0$; $k = 0$;
$p\_id = rand()\%N_p$;
Random Access Procedure;
while during a period **do**
  if receiving contention resolution **then**
    k++;
    if contention resolution identity is equal to UE_identity **then**
      $T\_ID = t\_id$; $F\_ID = f\_id$; $P\_ID = p\_id$;
      return
    end if
  else
    $t\_id = rand()\%BI$;
    $f\_id = rand()\%M$;
    $p\_id = rand()\%N_p$;
    Random Access Procedure
  end if
end while

PRACH has not been changed in next access period, the devices would use the previous successful contention information to re-attach to the network. In other words, the devices will inherit the same contention resource from the previous successful experience. Otherwise, if the MTC PRACH has been changed, the MTC devices are aware that the system desire to compact the contention patent. They calculate the previous successful information and use adjusted contention resources for next contention. Assuming that S_n is the number of successful contentions in the n-th frame, N is the total number of MTC devices in the cell. Therefore, the k-th contention attempt among N MTC devices is given by,

$$k = \sum_{n=1}^{i-1} S_n + m, \tag{1}$$

where the notation m is a value representing the m-th contention attempt in the i-th frame.

The k-th contention attempt chooses an adaptive preamble p in the f-th frame, we have,

$$f = \left\lceil \frac{k}{N_p} \right\rceil, \tag{2}$$

$$p = k\%N_p. \tag{3}$$

By the calculation, one preamble is only used for one device. Therefore, there is a one to one mapping between the radio contention resources and MTC devices. If any collision still occurs during phase number two, the device shall perform

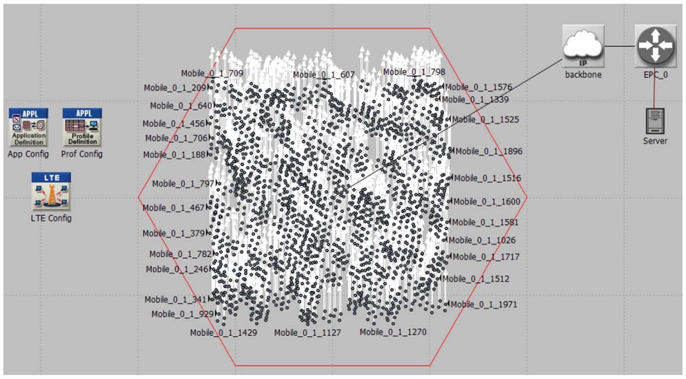


Fig. 3. MTC simulation model.

specific random backoff and return to the phase number one. Otherwise, the device would memorize and reuse the new contention resource over every reporting period. The algorithm of compact phase is shown as below, where AT_ID, AF_ID, and AP_ID represent the time index of the chosen subframe of RACH resource after self-adaptive contention scheme, the specified RACH resource within that subframe after self-adaptive contention scheme, and the index of the chosen random access preamble after self-adaptive contention scheme, respectively.

Algorithm 2: Compact phase

Input: The successful contention information (T_ID, F_ID, P_ID, k).
Output: The self-adaptive contention information (AT_ID, AF_ID, AP_ID).

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if RACH configuration has been changed then
    if frame structure type is equal to 1 then
        AT_ID = ⌈k/N_p⌉; AF_ID = 0;
        AP_ID = k%N_p;
    else if frame structure type is equal to 2 then
        AT_ID = ⌈k/(N_p · M)⌉;
        AF_ID = ⌈[k%(N_p · M)]/N_p⌉;
        AP_ID = [k%(N_p · M)]%N_p;
    end if
    Random Access Procedure
    return
else
    inherit (T_ID,F_ID, P_ID) to contend
    return
end if
```

IV. Simulation Results

To evaluate the performance of the proposed contention scheme, the simulation is executed by OPNET with the reference of the traffic model. The simulation assumptions and methodologies are defined in TR 37.868 specification [17]. In order to compare the performance of standard random access scheme adopted by the MTC in LTE networks and proposed SPC protocol, the access success probability, number of preamble transmissions, and access delay are used as the primary metrics. To concentrate on the performance of SPC scheme, 2000 mobile nodes, one eNB and one server in the designed simulation model are assumed in the OPNET simulator as shown in Fig. 3. According to the network performance investigation under different access intensities [17], two different traffic models, uniform and beta distributions, are assumed. The former traffic model can be considered as a realistic scenario in which MTC devices access the network uniformly over a period of time such as in a non-synchronized manner. The latter traffic model can be considered as an extreme scenario in which a large amount of MTC devices access the network in a highly synchronized manner, for example when earthquake happens. Considering mechanisms of RAN overload control must be designed without a significant impact on H2H traffic, so we analyze the impact to H2H devices under these new contention schemes. Therefore, the simulation conditions have to include H2H traffic. The H2H traffic is set to seven calls per second [19] [20].

TABLE I
System parameters

Parameter	*value*
Cell bandwidth	5 MHz
UL-DL allocations configuration	1
PRACH Configuration Index	6
Total number of preambles	4
Maximum number of preamble transmission	10
Number of UL grants per RAR	3
Number of CCEs allocated for PDCCH	16
Number of CCEs per PDCCH	4
Ra-ResponseWindowSize	5 subframes
mac-ContentionResolutionTimer	48 subframes
HARQ retransmission probability (non-adaptive HARQ)	10%
Maximum number of HARQ TX (non-adaptive HARQ)	5
Contention Period (CP)	5ms, 10ms, 20ms
Number of PUSCH RBs (per subframe)	23

Despite 3GPP has defined the beta and uniform distribution for MTC simulation, we do not consider that the two distributions are suitable for scheduling based MTC devices. For the sake of using uniform distribution, the access success probability is 100%. The phenomenon is still not realistic because the amount of access attempts are distributed over all simulation time averagely. Therefore, we use burst distribution with EAB scheme as the traffic model to simulate that the amount of requests arrive simultaneously at the beginning of MTC PRACH.

The RACH opportunities are defined as the number of users including MTC devices and H2H devices who can access the network. The RACH are configured to occur in every 5ms. There are four preambles in every RACH. This assumption results in 200 RACH opportunities per second and a total of 800 preambles per seconds. If two or more MTC devices select the same preamble at the same time, the eNB is not

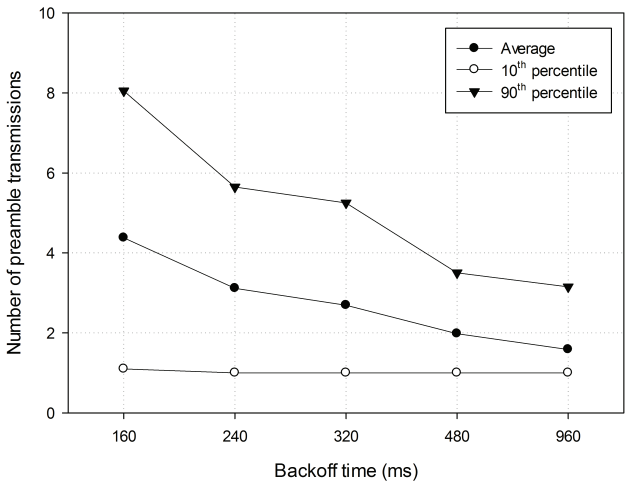

Fig. 4. Comparisons of simulation results of preamble transmissions as a function of backoff time under contention period 5ms after the contention phase.

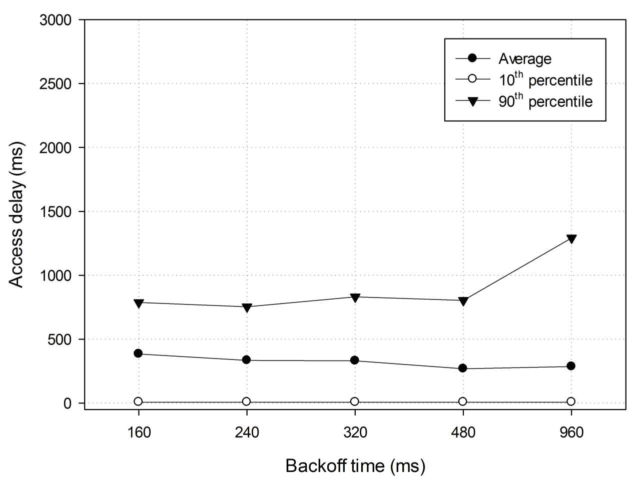

Fig. 5. Comparisons of simulation results of access delay as a function of backoff time under contention period 5ms after the contention phase.

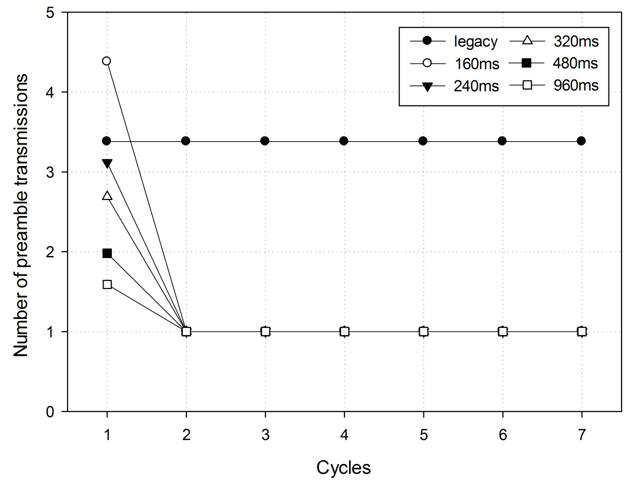

Fig. 6. Comparisons of simulation results of preamble transmissions as a function of cycle under contention period 5ms after the compact phase.

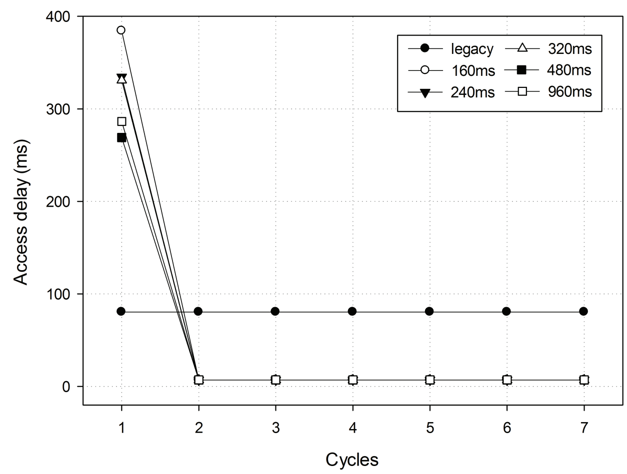

Fig. 7. Comparisons of simulation results of access delay as a function of cycle under contention period 5ms after the compact phase.

able to decode any of the preambles; hence, the eNB does not send the RAR. MTC devices detect a collision if RAR is not received during the RAR window. In realistic, eNB still has the probability to decode successfully because of capture effect. The MTC device detect a collision not only when its RAR window is expired but also when it receive contention resolution with unmatched UE identity. All the simulation parameters are based on the MTC simulation defined in TR 37.868 specification [17]. The basic simulation parameters are listed in Table I.

The simulation results of RACH capacity under 5ms contention periods is shown as Table II. In Fig. 4, we can observe that the number of preamble transmissions decreases when the backoff time extends in the contention phase. Although the access delay of 90th percentile devices is obvious longer when the backoff time is set to 960ms in Fig. 5, the delay in MTC is negotiable under different deployment conditions and the mean delay is almost the same with backoff time setting to 480ms.

To figure out the best performance for the proposed scheme, we simulate the 5ms contention period at compact phase. When the contention phase is end, the eNB changes the MTC PRACH to minimize the access requirement. Although the overhead of contention is high in phase number one, the MTC devices obtain sufficient information for self-adaptive. From Fig. 6 and Fig. 7, we can observe that the procedure in the compact phase is worthy. The access success probability, re-attempt count, access delay are optimal after the second cycle. The MTC devices memorize the adaptive information for every reporting cycle. The proposed SPC scheme shows better performance than the standard MTC random access scheme.

TABLE II
PHASE 1 RACH CAPACITY UNDER CONTENTION PERIOD 5MS

Performance measures		Contention period (5ms)				
Backoff time (ms)		160	240	320	480	960
Access success probability		100%	100%	100%	100%	100%
Number of preamble transmissions	Average	4.38	3.12	2.69	1.98	1.59
	10th percentile	1.1	1	1	1	1
	90th percentile	8.05	5.65	5.25	3.5	3.15
Access delay (ms)	Average	384.35	334.6	330.95	269.05	286.32
	10th percentile	8	7	7	7	7
	90th percentile	787	753.75	831.25	803.5	1292
Percentage of RBs for PRACH		5.2%(H2H), 5.2%(MTC)				

V. CONCLUSION

This paper has revealed that the primary reasons of high collision rate in the MTC random access scheme are twofold: large number of MTC devices with little traffic requirement and the overhead of contention protocol. In this paper, we have proposed a novel contention scheme to solve the collision problems generated by MTC devices which have periodical reporting cycles. The goal of this work is to increase the access probability and reduce the number of preamble transmissions of MTC devices. Furthermore, the proposed scheme has to mitigate the impact to H2H devices and optimize the uplink bandwidth utilization of MTC devices.

With SPC scheme, the MTC devices only contend on MTC PRACH, which is not used by H2H. The MTC PRACH occupies the RBs of PUSCH. In this way, H2H devices are not influenced by MTC access traffic. Furthermore, we design a self-adaptive convergence method to minimize the percentage of additional RBs used by MTC PRACH. Finally, the MTC devices memorize the optimized contention information to achieve contention-free RACH. From the simulation results, the access success probability is almost 100% under EAB mechanism and the 960ms backoff value. Although the access delay of the contention in the proposed scheme is longer than that in the legacy scheme at first, it is still fine because MTC devices are defined as time tolerance UEs. In compact phase, the contention becomes more efficient. Therefore, every MTC device can adjust itself using a dedicated contention resource to access the network. The success probability, the access delay and the number of preamble transmissions are optimized.

For further work, our research which follows the 3GPP specifications and contributions of 3GPP regular meetings would consider a variable number of new coming 3GPP MTC devices and error-prone channel conditions in the analysis and simulation models under more realistic scenario.

ACKNOWLEDGMENT

This research was supported by the Institute for Information Industry (III) of Taiwan through Advanced Wireless Broadband System and Inter-networking Application Technology Development Project.

REFERENCES

[1] 3GPP TS 22.368 V11.3.0, "Service requirements for Machine-Type Communications (MTC);Stage 1," Sept. 2011.
[2] Draft ETSI TS 102 689 V0.4.1 (2009-mm), "Machine-to-Machine communications (M2M)," *M2M service requirements*, 2009.
[3] 3GPP TR 22.868 V8.0.0, "Study on Facilitating Machine to Machine Communication in 3GPP Systems," Mar. 2007.
[4] 3GPP TR 33.812 V9.2.0, "Feasibility study on the security aspects of remote provisioning and change of subscription for Machine to Machine (M2M) equipment," Jun. 2010.
[5] 3GPP TS 36.321 V10.2.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification," Jun. 2011.
[6] 3GPP TS 25.913 V9.0.0, "Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN)," Dec. 2009.
[7] 3GPP TS 36.300 V11.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description, Stage 2," Dec. 2011.
[8] 3GPP TS 36.101 V10.4.0, "User Equipment (UE) radio transmission and reception," Sept. 2011.
[9] 3GPP RAN2 69bis, R2-102296, "RACH Intensity of Time Controlled Devices," *Vodafone*, Apr. 2010.
[10] 3GPP RAN2 69bis, R2-102297, "RAN Mechanisms to Distribute RACH Intensity," *Vodafone*, Apr. 2010.
[11] 3GPP RAN2 70, R2-103269, "Modifications to RACH Intensity of Smart Meters in TR 37.868," *Institute for Information Industry (III), CHTTL, Coiler Corporation*, May 2010.
[12] 3GPP RAN2 70bis, R2-103973, "RACH collision probability analysis," *Huawei*, Jul. 2010.
[13] 3GPP RAN2 70bis, R2-103742, "RACH overload solutions," *ZTE*, Jul. 2010.
[14] 3GPP RAN2 70bis, R2-103776, "Separate backoff scheme for MTC," *ETRI*, Jul. 2010.
[15] GPP RAN2 70bis, R2-103907, "Solutions for RACH overload," *Ericsson, ST-Ericsson*, Jul. 2010.
[16] 3GPP TS 25.331 V10.5.0, "Radio Resource Control (RRC) protocol specification," Sept. 2011.
[17] 3GPP TR 37.868 V11.0.0, "Study on RAN Improvements for Machine-type Communications," Sept. 2011.
[18] 3GPP RAN2 73bis, R2-113650, "Report of 3GPP TSG RAN WG2 meeting #73bis, Shanghai, China, April 11 - 15, 2011," *ETSI MCC*, Apr. 2011.
[19] 3GPP RAN2 70bis, R2-104663, "LTE: MTC LTE simulations," *ZTE*, May 2010.
[20] 3GPP TR 23.888 V1.6.0, "System Improvements for Machine-Type Communications," Nov. 2011.