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셀룰러 기반의 사물 간 통신을 위한 임의접근 채널의 부하 제어 알고리즘

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Overload Control for Random Access in Cellular Machine-to-Machine Communications

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요 약

본 논문에서는 셀룰러 기반의 사물 간 통신 네트워크에서의 임의접근채널 과부하 문제를 해결하기 위한 부하제어 기법을 제안한다. 사물 간 통신 단말은 기존 이동통신 단말에 비해 매우 높은 밀도로 분포하며 주로 간헐적으로 짧은 데이터를 전송하는 특성을 가지고 있다. 이러한 특성으로 인해 임의접근 기반으로 기지국에 접속하게 되는데 이 때 다수의 사물 간 통신 단말이 기지국 임의접근 채널에 신호를 전송하는 경우 임의접근 채널에 과부하가 일어날 수 있다. 그러므로 본 논문에서는 이러한 문제를 해결하기 위해 기지국이 네트워크의 부하를 측정하고 이를 바탕으로 p-persistent 방식을 이용해 부하를 제어하는 기법을 제안한다.

ABSTRACT

In this paper, we propose an overload control scheme to resolve an overload problem in a random access channel of cellular machine-to-machine (M2M) communication networks. The M2M applications are characterized by small-sized data intermittently transmitted by a massive number of machines. Due to this characteristics, an overload situation in random access channel (RACH) can happen when a large number of devices try to send a signal via the RACH. To address this overload problem, we propose a scheme in which a base station estimates the total load in the network and controls the load by using a p-persistent method based on the estimated load.

키워드

Machine-to-Machine Communication, Overload Control, Cellular Networks, LTE
사물 간 통신, 부하제어, 셀룰러 네트워크, LTE

Ⅰ. Introduction

In recent years, the machine-to-machine (M2M) communications in cellular networks such as Long-Term Evolution (LTE) [1][2] has attracted great attention [3]. However, since the traditional cellular network is engineered for human-to-human (H2H) traffic, it is considered not suitable for M2M communications. The M2M applications are characterized by small-sized data intermittently transmitted by a massive number of machines. Due to this characteristics, an overload problem in random

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access channel (RACH) is identified as a prominent problem of M2M in LTE networks.

In this paper, we propose an overload control scheme to resolve the overload problem in cellular M2M communications. The proposed scheme estimates the total load in the system by means of a Bayesian tracking algorithm. Then, the proposed scheme controls the participation of user equipments (UEs) in the random access procedure by using a p-persistent method.

Section Ⅱ introduces related works. In Section Ⅲ, we explain the system model. Section Ⅳ describes the proposed overload control scheme in detail. The simulation result is presented in Section Ⅴ, and the paper is concluded in Section Ⅵ.

Ⅱ. Related Works

This section explains some related works. Since most of M2M applications have the characteristics that there are a tremendous number of M2M UEs in a given area, which causes the overload problem. A hierarchical model is proposed to reduce overhead signaling in a cellular radio access network (RAN) [4]. By making M2M UEs first send the data to a data concentrator before sending it to base station, the total signaling overhead in the RAN of the cellular system is dramatically decreased. However, by adding additional hops, the process for handling a single M2M UE gets longer, making this solution cannot be used for applications that need low latency. This solution also requires M2M UEs to be installed not too far from the data concentrator, making it inapplicable or too expensive for some applications.

Another approach is grouping the devices into several groups depending on the priority. Each group has different overload control parameters according to its priority. The control parameters can be an access class barring parameter, a back off parameter, or slot allocation. The works that propose this kind of approaches are [5], [6], and [3]. The main idea of this approach is to disperse the access of the devices, especially the low priority devices so that the higher priority devices can access RAN easily with a very low collision probability. Though this method can work well in the simulation, these works do not give a detailed guide to how to control the overload by using the information available to RAN.

Some works redesign the procedures for M2M communications to improve the latency and resource usage [7]-[9]. The authors of [7] proposes a contention based access channel for M2M communications. In [8], the authors propose a procedure that allows M2M devices to send the data in the authentication procedure. In [9], the authors make use of timing advance information to enhance the throughput in the random access channel (RACH). Although these previous works propose a new design of transmission procedure for M2M communications, none of these works study the issue of overload control schemes..

Other than the cellular M2M communications, the research works on the M2M communications based on the RFID and ZigBee technologies have been published (e.g., [10]-[12]). In [10], the authors propose a WiMedia MAC based on RFID cooperative relay transmission scheme for warehouse management system applications. In [11], the authors analyze the existing bus information system, as the basis of the results obtained, and design an experimental bus information system, which is based on a computer, a ZigBee communication, and several line tracers. In [12], a system using vibrating wire sensor and ZigBee wireless networks has been implemented to monitor and manage the structure.

Ⅲ. System Model

3.1. Random Access Procedure

In this paper, we define a cycle as a basic time unit for the random access procedure. At the start of each cycle, a physical random access channel (PRACH) is placed. In each cycle, a UE, which tries to perform random access, chooses one preamble out of all orthogonal preambles available in the PRACH. The number of available preambles in a PRACH is denoted by S.

If a UE selects a preamble which is not selected by any other UE, the random access of the UE can be successful. On the other hand, if two UEs select the same preamble, collision happens. To prevent overload condition, in which an excessive number of collisions happen, we adopt a p-persistent overload control algorithm. In this algorithm, the BS decides the random access probability P_t in cycle t and broadcasts P_t before cycle t starts. A UE initiates random access with the probability P_t in cycle t.

The BS tries to detect the preambles sent by UEs in the cell. Upon detecting a preamble, the BS sends the random access response (RAR) via a downlink channel. The RAR conveys the identity of the detected preamble and an initial uplink resource grant. When a UE receives an RAR corresponding to the selected preamble, the UE can send the layer 2/3 message (e.g., an RRC connection request and a scheduling request) by using the initial uplink resource grant in the received RAR. If the BS succeeds in receiving the layer 2/3 message, the BS sends the contention resolution message with the identity of the UE contained in the received layer 2/3 message. The random access procedure is completed if the UE receives the contention resolution message with its own identity.

3.2. System Parameters

We define an active UE as a UE that is ready to initiate a random access procedure. Let N_t denote the number of active UEs at the start of cycle t. An active UE sends a preamble via a PRACH in cycle t with probability P_t. To send a preamble, each UE chooses one preamble out of S preambles. Let $M_t^{(s)}$ denote the number of UEs that selects preamble s in cycle t.

A random access procedure of a UE is successfully finished when no other UE sends a preamble on the same preamble. Let $H_t^{(s)}$ denote the number of UEs which succeed in completing random access, among the UEs selecting preamble s in cycle t. Then, we have $H_t^{(s)}=1$ if $M_t^{(s)}=1$; and $H_t^{(s)}=0$, otherwise.

A UE, which fails in random access in cycle t, makes an attempt again in cycle $(t+1)$. The number of the reattempting UEs in cycle $(t+1)$ is $N_t-\sum_{s=1}^{S}H_t^{(s)}$. In addition to these reattempting UEs, new active UEs arrive at the system for random access. Let A_t denote the number of new active UEs. We assume that A_t follows a Poisson distribution with mean λ. Then, we can calculate the number of the active UEs in cycle $(t+1)$ as

$$N_{t+1}=N_t-\sum_{s=1}^{S}H_t^{(s)}+A_t \tag{2}$$

At the end of each cycle, the BS knows the outcome of each preamble. Let $O_t^{(s)}$ denote the outcome of preamble s in cycle t. Then, $O_t^{(s)}=-1$ if a collision happens in preamble s; $O_t^{(s)}=0$ if there is no UE sending preamble s; and $O_t^{(s)}=1$ if a UE succeeds in random access via preamble s. We define the vector of the outcomes of all preambles in cycle t as $O_t=(O_t^{(1)},...,O_t^{(S)})^T$ and define the history of the outcomes from cycle 1 to cycle t as $\overline{O_t}=\{O_1,...,O_t\}$.

Ⅳ. Proposed Overload Control Scheme

4.1. Bayesian Tracking Algorithm

For overload control, the BS decides the random access probability P_t before cycle t starts. To find an appropriate random access probability, it is crucial for the BS to know the current number of active UEs. However, the BS cannot know N_t. Therefore, we investigate the Bayesian tracking algorithm to estimate N_t based on the history of outcomes $\overline{O_t}$.

The BS maintains the estimate of the average number of active UEs by means of the Bayesian tracking algorithm. Let Q_t denote the estimate of the average number of active UEs in cycle t. The BS evaluates Q_t based on $\overline{O_{t-1}}$. Therefore, from the standpoint of the BS, Q_t is defined as

$$Q_t = \mathrm{E}[N_t \mid \overline{O_{t-1}}] \tag{3}$$

In cycle $(t+1)$, the BS updates the previous estimate Q_t to the current estimate Q_{t+1} on the basis of the new outcome O_t. We can calculate Q_{t+1} as

$$\begin{aligned} Q_{t+1,c} &= \mathrm{E}[N_{t+1} | \overline{O_t}] \\ &= \mathrm{E}[N_t - \Sigma_{s=1}^{S} H_t^{(s)} + A_t | \overline{O_t}] \\ &= (1-P_t)\,Q_t + \lambda \\ &\quad + \Sigma_{s=1}^{S} I_{(O_t^{(s)}=-1)} \mathrm{E}[M_t^{(s)} | O_t^{(s)} = -1, \overline{O_{t-1}}] \end{aligned} \tag{4}$$

where $I_{(X)}$ is 1 if X is true, and is 0 otherwise.

In (4), $\mathrm{E}[M_t^{(s)} | O_t^{(s)} = -1, \overline{O_{t-1}}]$ is the average number of UEs, which send preambles on RAO s, under the condition that a collision happens on preamble s. To calculate this, we assume that N_t conditioned on $\overline{O_{t-1}}$ follows a Poisson distribution with mean Q_t. Then, we can calculate $\mathrm{E}[M_t^{(s)} | O_t^{(s)} = -1, \overline{O_{t-1}}] = f(P_t, Q_t)$, where

$$f(P_t, Q_t) = \frac{P_t Q_t / S\,(1-\exp(-P_t Q_t/S))}{1-(1+P_t Q_t/S)\exp(-P_t Q_t/S)} \tag{5}$$

From (3)-(5), the proposed scheme updates Q_t as

$$Q_{t+1} = (1-P_t)\,Q_t + \lambda + L_t\, f(P_t, Q_t) \tag{6}$$

where L_t is the number of preambles in which a collision happens, i.e., $L_t = \Sigma_{s=1}^{S} I_{(O_t^{(s)}=-1)}$. At the end of cycle t, the BS obtains L_t and calculates Q_{t+1} by using (6).

4.2. Overload Control Scheme

The overload control scheme decides the random access probability P_t every cycle based on the estimate Q_t. The aim of the overload control scheme is preventing the overload condition in random access by maximizing the throughput. If we assume that the estimation Q_t is accurate, the throughput is calculated as

$$E[\Sigma_{s=1}^{S} H_t^{(s)} \mid \overline{O_{t-1}}] = P_t Q_t \exp(P_t Q_t / S) \tag{7}$$

This throughput is maximized when $P_t Q_t / S = 1$. Therefore, in the proposed scheme, the BS decides P_t as

$$P_t = S / Q_t \tag{8}$$

if $Q_t \geq S$; and $P_t = 1$, otherwise.

Ⅴ. Simulation Result

By simulation, we show the operation of the proposed scheme over cycles in Fig. 1. The parameters are as follows : $S = 180$ and $\lambda = 50$. At cycle 50, a large number of UEs (i.e., 1000 UEs) suddenly arrive in the system. We can see that the proposed scheme can handle this overload situation very well by tracking the number of active UEs and by reducing the random access parameter accordingly.

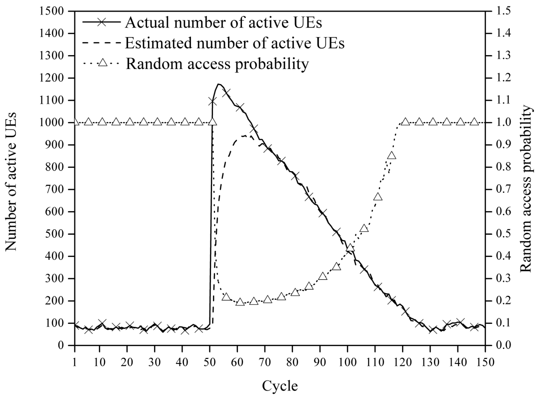

Fig. 1 Operation of the proposed scheme over cycles

Ⅵ. Conclusion

In this paper, we have proposed the overload control scheme for the cellular M2M communications. By simulation, we have shown that the proposed scheme effectively controls the overload situation.

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