A Novel Power Ramping Scheme of M2M for WCDMA Random Access Channel

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Abstract—**Machine-to-Machine (M2M) communication is rising to prominence in wireless communication. Due to various advantages, the cellular networks, which are designed and optimized for Human-to-Human (H2H) communication, have been considered as one of the best choices to bear M2M service. However, because of the specific characteristics of M2M communication, there must be many incompatible factors in practice, and the Random Access (RA) performance of H2H communication will also be affected severely. To evolve and develop competitive capabilities to support M2M communication, the system model of RA is built firstly, and then one power ramping strategy based on Logarithm is proposed for M2M. Numerical results show that the proposed algorithm can greatly improve H2H RA performance while maintaining the throughput of M2M communication. Meanwhile, the proposed strategy can also reduce the M2M transmit power to extend the battery life.**

Keywords-Internet of Things (IoT); machine-to-machine (M2M); human-to-human (H2H); power ramping scheme; Wideband Code Division Multiple Access (WCDMA);

I. INTRODUCTION

Internet of Things (IoT) refers to a huge network which is formed with Internet and different kinds of information sensing devices [1]. As the third scientific and economic tide after the computer and Internet, it has brought an enormous new market for the communication industry. Generally, M2M communication mainly focuses on the equipment and network technologies, which involves a mass of intelligent machines sharing information and making autonomous decisions without or with limited human interventions [2]. As the early development form of IoT, M2M communication has attracted more and more attentions from research institutes and universities.

M2M communication has been applied in many fields, such as smart city, fleet management, and automatic tolling[3]. Currently, traditional cellular networks, with the advantages of low-cost and large coverage, have nearly spread to every corner of the world, and have been considered as one of the best choices to bear M2M communication. However, unlike H2H communication, M2M communication has many typical characteristics, viz., mobile originated, packet switch data, low mobility, a large number of potential communicating terminals, little traffic per device [3][4]. When M2M communication is carried on the existing network, which is designed and optimized for traditional H2H communication, there must be a lot of incompatible factors. With the increasing M2M market, providing efficient communication for M2M has become a serious challenge[5].

Currently, under the tempting market prospect, more and more M2M applications have been implemented in current 2G/3G networks. The WCDMA System, as the most efficient system at present, has been taken into consideration for realizing various M2M applications. In such system, random access (RA) procedure is based on the Slotted Aloha with acquisition indication, and the transmission of the random access request (RAR) contains two steps: preamble transmission and message transmission. The mobile station (MS) needing to access to the network must select the available access slots and the available orthogonal signatures firstly. Other parameters used in the whole transmission such as the transmission power range, the maximum number of retransmissions, and the power control parameters are received from the higher layer messages [6][7]. Due to the long set-up time, it’s impossible to use closed loop-power control in the Random Access Channel (RACH) procedure. But the open loop power control schemes can’t ensure the accuracy. As a result, the power ramping is introduced. In this approach, the first transmission is done with a power level suggested according to the path loss estimated, if the transmission attempt is unsuccessful, power is increased by the negotiated stepwise in each additional attempt in order to certificate success rate. Large ramping step-size can serve to decrease delay but it results in unwanted interference. Therefore, a moderate ramping scheme is considered as the key factor to ensure network efficiency.

In the previous research, the random access transmission with both non-power ramping and power-ramping retransmission was investigated analytically in [7], where a message flow method was employed. In [9], the RACH performances were evaluated through multiple metrics covering average target power, throughput, blocking probability, and delay statistics under several power ramping schemes. In [10], access slots and spreading codes are

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grouped for different traffic classes. All the previous researches focus on the traditional H2H communication. However, there is little related research on the co-existing traffic of M2M and H2H communications. Furthermore, the present researches on M2M mainly focus on the RAN overload solutions [11] and the transport protocols simplification to avoid redundant signaling overheads [12], while little attention has been devoted to power ramping schemes in the RACH.

In this paper, the RA analysis model for H2H and M2M coexisting scenario is built firstly, which is corresponding to the analysis about single traditional H2H service in [9], and then a power ramping strategy based on Logarithm for M2M is proposed to obtain the optimal solution. Numerical results illustrate that the proposed scheme can improve H2H access performance greatly while maintaining the throughput of M2M service and minimizing the energy consumption obviously.

This paper is organized as follows. In Section II, the system model is built. Current power ramping schemes and the new proposed ramping schemes are presented in Section III. Section IV shows the RA simulation results based on the analytic models above, under the existing and the proposed methods. Section V concludes the paper.

II. SYSTEM MODELS

The problem model in this paper is based on the flow of RA in Fig.1. Assume that M2M and H2H traffic are both generated by Poisson processes, with the variable arrival rate G_1 and G_2 respectively, both of which include initial transmissions and retransmissions. If N_i denotes the number of the i^{th} user contending for the same slot, where i=1 is for M2M and i=2 for H2H respectively, the distribution of N_i can be described as

$$P\{N_i = n_i\} = \frac{G_i^{n_i} e^{-G_i}}{n_i!}, n_i = 0,1,2.......,i = 1,2 \tag{1}$$

Suppose Q be the number of available signature codes that can be used to initiate RACH request. For the given device A, let n_s be the UE number of the same kind accessing network with the same slot and k_s be the number of the same kind UEs colliding with the given device A. Similarly, the number of other kind of UEs that collide with A in the same slot can be denoted by n_d and k_d respectively. Given K_s, K_d and Q, the probability that the UE collides with exactly $k_s + k_d$ UEs can be expressed as below.

$$\begin{aligned} &P\{K_s = k_s, K_d = k_d \mid N_s = n_s, N_d = n_d\} \\ &= P\{K_s = k_s \mid N_s = n_s\} \times P\{K_d = k_d \mid N_d = n_d\} \end{aligned} \tag{2}$$

where

$$\{K_s = k_s \mid N_s = n_s\} = \begin{cases} \binom{k_s}{n_s - 1}\left(\frac{1}{q}\right)^{k_s - 1}\left(\frac{q-1}{q}\right)^{n_s - k_s}, & 1 \le k_s \le n_s \\ 0, & n_s = 0 \end{cases} \tag{3}$$

$$\{K_d = k_d \mid N_d = n_d\} = \begin{cases} \binom{k_d}{n_d}\left(\frac{1}{q}\right)^{k_d - 1}\left(\frac{q-1}{q}\right)^{n_d - k_d}, & 0 \le k_d \le n_d \\ 0, & n_d = 0 \end{cases} \tag{4}$$

In the analysis model, a Rayleigh frequency-selective fading channel is employed. Assuming the open-loop power control can perfectly compensate shadow effects, the signal envelope in one path can be expressed by a Rayleigh random variable. If the RAKE receiver at BS side has L fingers, the signal power P aggregated from the distributed L independent paths can be denoted by a gamma variable. Let μ be the average received power from each path, then the probability distribution of the received power is

$$f_P(x) = \frac{x^{L-1}\exp(-\frac{x}{\mu})}{(L-1)!\mu^L}, x > 0 \tag{5}$$

In the RAKE receiver, the BS aggregates the preamble transmission from the other $k_s + k_d - 1$. Compared with the interference from massive of MDs and Multiple Access Interference, the additive channel noise and self-interference are negligible. Denote β_1 as the minimum Signal-to-Interference Ratio (SIR) at the BS side for decoding the preamble successfully. Then, when the condition below is satisfied, the BS can decode preamble from the blending ones.

$$\frac{P_A + \sum_{i=2}^{k_s} P_i + \sum_{j=1}^{k_d} P_j}{\sum_{i=k_s+1}^{n_s} P_i + \sum_{j=k_d+1}^{n_d} P_j} \ge \beta_1 \tag{6}$$

where P_i, P_j and P_A represent the received power from UE-i, UE-j and the device A respectively.

Given N_1, N_2 and K_1, K_2, the conditional success probability of the i^{th} users for the r^{th} preamble retransmission can be derived from (5), i.e.,

$$u(r \mid n_s, n_d, k_s, k_d) = \begin{cases} \frac{1}{(1+\beta_1)^b} \times \gamma & 1 \le k_s + k_d \le (n_s + n_d - 1) \\ 1 & k_s + k_d = n_s + n_d \end{cases} \tag{7}$$

where

$$\gamma = \sum_{i=0}^{a-1} \frac{(b+i-1)!}{i!(b-1)!} \times \left(\frac{\beta_1}{1+\beta_1}\right)^i \quad 1 \le k_s + k_d \le (n_s + n_d - 1) \tag{8}$$

$$\begin{cases} a = \lfloor (k_s + k_d - 1)\overline{m}L + m(i,r)L \rfloor \\ b = \lfloor (n_s + n_d - k_s - k_d)\overline{m}L \rfloor \end{cases} \tag{9}$$

Referring to (8), $m(i,r)$ is the target power level of the i^{th} kind of users for the r^{th} retransmission, $\lfloor x \rfloor$ is the floor function, and the average target power level of each device in the system is expressed as $\overline{m}$, which can be determined by

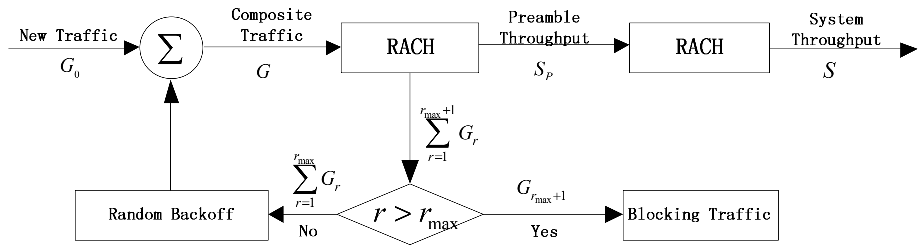

Figure 1 Flow diagram of the RA procedure

$$\begin{aligned}\overline{m} &= \sum_{i=1,2}\sum_{r=0}^{r_{max}} m(i,r)\frac{G(i,r)}{G} \\ &= \sum_{i=1,2}\Big(\frac{1+\sum_{r=0}^{r_{max}}\Big\{m(i,r)\prod_{l=0}^{r-1}[1-u(i,l)]\Big\}}{1+\sum_{r=1}^{r_{max}}\prod_{l=0}^{r-1}[1-u(i,l)]}\Big)\times\frac{G(i)}{G}\end{aligned} \tag{10}$$

Removing the conditions on n_s, n_d, k_s, k_d, the r^{th} retransmission success probability of the i^{th} users can be derived from (6),

$$\begin{aligned}u(i,r) = &\sum_{n_1=1}^{\infty}\sum_{n_2=0}^{\infty}\sum_{k_s=1}^{n_1}\sum_{k_d=0}^{n_2} u(r \mid n_s,n_d,k_s,k_d) \\ &\times\alpha\times P\{N_s = n_s-1\}\times P\{N_d = n_d\}\end{aligned} \tag{11}$$

where

$$\alpha = P\{K_1 = k_1 \mid N_1 = n_1\}\times P\{K_2 = k_2 \mid N_2 = n_2\} \tag{12}$$

It can be noticed that the success probability of the i^{th} kind of users for the r^{th} preamble retransmission is a function of $\overline{m}$. But $\overline{m}$ as expressed in (9) is a function of $u(i,r)$ in turn.

Assume $G(i,0)$ and $G(i,r)$ represent the arrival rate of the initial new transmission and the r^{th} preamble retransmission for the i^{th} kind of users respectively. When the system reaches the balance state, the blocking rate equals to the new arriving rate, and the r^{th} preamble arrival rate of i^{th} users $G(i,r)$ is able to be deduced from the flow in Fig.1.

$$\begin{cases} G(i,0) = S_P(i) + G_{r_{max}} \\ G(i,1) = G(i,0)[1-u(i,0)] \\ G(i,2) = G(i,1)[1-u(i,1)] \\ \cdots\cdots\cdots \\ G_{r_{max}+1} = G_{r_{max}}[1-u(i,r_{max})] \end{cases} \tag{13}$$

From the relationship of the multiple variables, the composite offered traffic (OT) $G_i = \sum_{r=0}^{r_{max}} G(i,r)$ will be obtained, and the preamble throughput of the i^{th} kind users can be denoted by

$$S_P(i) = G_i \times \frac{1-\prod_{i=0}^{r_{max}}[1-u(i,r)]}{1+\sum_{r=1}^{r_{max}}\prod_{i=0}^{r-1}[1-u(i,r)]} \tag{14}$$

After r_{max} unsuccessful retransmissions, the preambles are blocked. The blocking probability of the preamble transmission is therefore

$$P_B(i) = P\{R_i > r_{max}\} = \prod_{r=0}^{r_{max}}[1-u(i,r)] \tag{15}$$

III. POWER RAMPING MODELS

A. The Existing Power Ramping Schemes

The open-loop power control is applied during the RA procedure. When mobile stations (MSs) fail to get through the RA procedure, they will retransmit the request with a higher power to guarantee the success rate. In practice, there are several power schemes, such as fixed ramping, linear ramping and geometric ramping. In this paper, it's mainly focused on the first two schemes. For the initial preamble transmission, it's supposed that all the M2M and H2H UEs have the same target power level μL, and each UE taking the r^{th} retransmission with transmit power $m_r \mu L$, where μL is the power ramping unit, and m_r under different schemes can be described as follows.

Fixed ramping: the power step is fixed at one unit each time, i.e., $m_r = r+1$;

Linear ramping: the power step is increased by one unit each time, i.e., the r^{th} retransmission power is $m_r = \frac{r(r+1)}{2} + 1 = \frac{r^2+r+2}{2}$.

B. Proposed Power Ramping Schemes

If M2M communication is treated with no difference from H2H communication, the interference generated from huge MDs is so severe that the performance of H2H communication can't be well guaranteed. Indeed, when the number of MDs reaches a threshold, H2H UEs even can't communicate with each other. Therefore, it is significant to design appropriate ramping scheme for M2M to ensure the performance of both M2M and H2H communication.

The main factors affecting M2M interference to H2H communication are the number of MDs and the power ramping schemes. Large ramping step can guarantee the success rate, but it induces serious interference to the H2H UEs and other MDs inevitably. The available solution to reduce the interference is either to decrease the target power of M2M devices, or to increase the power level of H2H devices. Considering that the WCDMA system is interference-limited, the former idea is adopted in this paper. And one power ramping scheme is proposed on the basis of logarithm steps for M2M to improve H2H communication performances. In other words, the transmit power step of MDs for the r^{th} retransmission is $\Delta m(1,r) = \ln(r+1) - \ln(r)$, and the r^{th} target power level is therefore $m(1,r) = 1 + \ln(r+1)$, where r ranges from 1 to r_{max}.

IV. NUMERICAL RESULTS

A. Input parameters

In practice, the minimum SIR required in WCDMA for correctly decoding preambles is 7dB. Taking account of the spreading gain in the transmission, the SIR threshold is set as $\beta_1 = -5dB$ in this paper. Other main parameters in the simulation are shown in Table I.

B. Results

In order to verify the efficiency of the proposed scheme, the results of the existing schemes is employed as reference. For the purpose of facilitating analysis below, here some symbols are explained at first. The combined scheme of M2M and H2H both with fixed ramping is expressed as combined scheme 1 (CS1), the combined scheme of M2M with fixed ramping and H2H with linear ramping is represented by combined scheme 2 (CS2), and the combined scheme of M2M with our proposed Logarithm ramping and H2H with fixed ramping is named as combined scheme 3 (CS3).

Figure 2 demonstrates the average system target power levels of different power ramping schemes with different M2M and H2H OT values. When the H2H OT is constant, the average target power level increases with M2M OT becoming larger, but the growth rate decreases. As for small G_1 and G_2, the proportion of the H2H is considerable, and the H2H performance is significantly affected by M2M service. When the M2M OT becomes larger, M2M traffic will be the major system service. So, the probability $u(2,r)$ gradually moves forward to zero. At the same time, referring to (7) and (8),

TABLE 1 BASIC PARAMETERS IN NUMERICAL SIMULATION

Parameters	Value
Number of Resolvable Paths	$L = 2$
Average Target Receive Power Each Path	$\mu = 1$
Number of Available Signatures	$Q = 16$
Minimum SIR Requirements	$\beta_1 = -5dB$
Maximum Number of Retransmission	$r_{max} = 5$

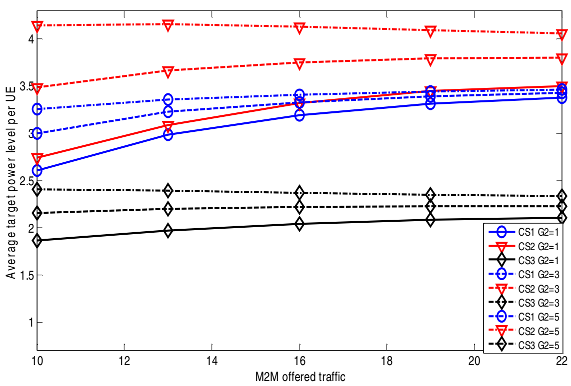

Figure 2 Average target power of preamble transmission.

when G_1 is larger than 18, the number of MDs in each available signature reaches to a relative balance. Therefore, the target power level grows in a moderate way. In addition, since the average power level represents the average transmit power of each user, it can be viewed as a measurement of interference caused by power ramping. Obviously, CS2 causes the highest interference to the ongoing H2H and M2M traffic.

As shown in Fig.2, when M2M and H2H OT are both fixed, CS3 is able to provide the lowest transmit power and the lowest interference compared with other CSs. Considering that WCDMA system is an interference-limited system, the proposed CS3 can greatly increase the system capacity, and improve the overall system performance.

The M2M and H2H throughputs of preamble transmissions are shown in Fig.3 and Fig.4 respectively. It is obvious that the throughput curve of H2H with $G_2 = 5$ changes more quickly than the other OTs. For the CS2, the throughput curves of H2H with $G_2 = 3$ and $G_2 = 5$ cross with each other when the M2M OT is 18. While in the other CSs, the throughput of H2H with OT $G_2 = 5$ is smaller than that with $G_2 = 3$. The reason for that can be described as follow. On the one hand, because of the large M2M OT value, it is inevitable that mass MDs compete for the limited resources with traditional UEs, which affect the H2H RACH performance severely. On the other hand, with the M2M OT increasing, the RA procedure of H2H becomes more and more difficult. As expected, large power step can increase the access success rate of H2H UEs. When the M2M OT doesn't reach the threshold, namely, M2M OT is smaller than18, the traffic ratio between H2H and M2M is considerable, and large power ramp scheme can provide a higher throughput with a slower change rate. But when M2M OT beyond the threshold, M2M traffic constructs major service of the system. In this case, the throughput of M2M and H2H decrease dramatically whichever the power scheme is applied.

With H2H OT increasing, the throughput of M2M traffic decreases linearly. When H2H OT is small, for example, $G_2 = 1$, the throughput of M2M under different ramping schemes is virtually the same. The effect of different schemes becomes increasingly apparent when the H2H OT becomes larger. As shown in Fig.3 and Fig.4, referring to the Fig.2, it can be seen that CS2 can get a higher throughput at the expense of stronger interference which restricts the whole network capacity severely.

The performance of H2H throughput can be greatly improved by CS3, while that of M2M is not affected apparently. Besides, it can be seen that the throughput of H2H under CS3 changes more gently, so it is more reliable than the existing schemes. Because the CS3 can get a higher throughput with the least power, it can save the M2M energy as much as possible.

Figure 5 illustrates the blocking probability of H2H under different ramping schemes for various M2M and H2H traffic. Referring to (15), P_B is the product of complementary success probabilities. When the throughput of the two kinds of users decreases, the blocking probability increases correspondingly. From the figure, it's obviously that the value of such probability is too high to guarantee the M2M and H2H communication quality. The blocking probability increases when both M2M and H2H OTs become larger. In addition, among three kinds of power ramping schemes, H2H service with linear power ramping can get a lowest blocking probability in CS2. Especially, when the H2H OT is small, i.e. $G_2 = 1$, the H2H blocking probability nearly reaches 0.

Considering the above three figures, compared with CS1, CS3 can provide a lower blocking probability and a higher throughput of H2H on condition that the M2M throughput is not affected apparently. Therefore, CS3 can make a good trade-off between the performance of throughput and blocking probability, and it's valuable for practical application.

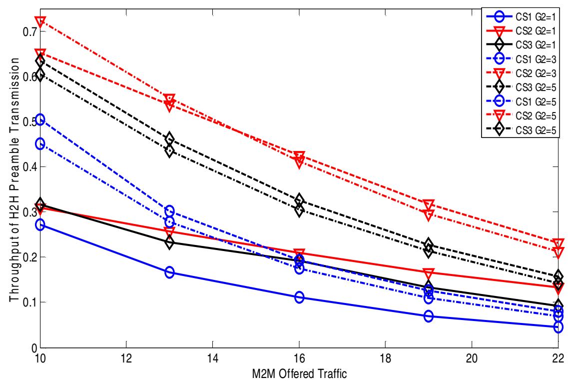

Figure 3 Throughput of H2H preamble transmission.

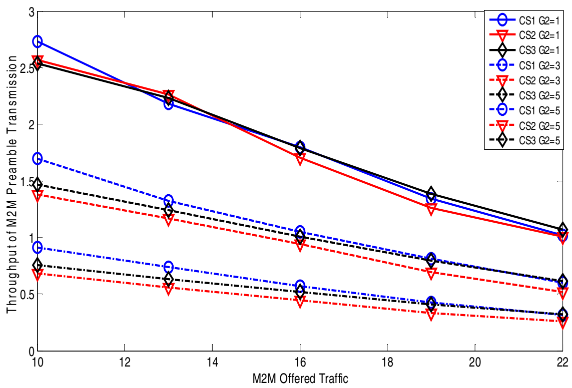

Figure 4 Throughput of M2M preamble transmission.

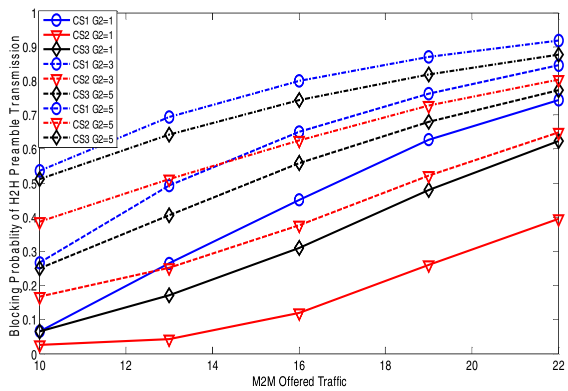

Figure 5 Blocking probability of H2H preamble transmission.

V. Conclusion

Power ramping schemes are used for WCDMA random access. In this paper, the analysis model is built firstly, and then a novel power ramping schemes is proposed based on the Logarithm for MDs. The throughput and blocking probability are studied under different power ramping schemes as well as the performance of mean transmit power is verified in the simulation. Beside the proposed scheme, the two existing schemes are also studied as comparison. Numerical results show that it is impossible to guarantee the RA performance of M2M and H2H services if M2M uses the power ramping scheme for H2H communication. With the proposed scheme, H2H performances can be greatly improved both in the throughput and blocking probability while maximizing the throughput of M2M traffic. In the meantime, the new scheme can reduce the power consumption of MDs to realize the concept of green communication.

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