

Performance Evaluation of Random Access for M2M Communication on IEEE 802.16 Network

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Abstract— M2M communication is information exchange between machines and machines without any human interaction. Standardization activities related to M2M communication are proceeding in many organizations due to the much applicability of M2M communication in various fields. One of the main issues for the M2M communication based on cellular network is the extremely large number of devices in service coverage. In cellular network which support contention-based random access scheme for network entry, the large number of devices lead to the problem in network entry process. For efficient network entry operation, new performance evaluation of random access for M2M communication on cellular network is needed.

Keywords— M2M, Random Access, IEEE 802.16

I. INTRODUCTION

M2M (Machine-to-Machine) communication is information exchange between machines and machines without any human interaction. The original concept of M2M communication was borne from telemetry technology, i.e. data gathering from remote source and automatic transmission of the data. Recently, M2M has become remarkable market with rapid development of wired and wireless communication technologies. The growth of M2M market caused by much applicability of M2M communication in various fields such as secured access and surveillance, tracking, tracing and recovery, public safety, sensor, vehicular telematics, healthcare monitoring of bio-sensors, remote maintenance and control, smart metering, automated services on consumer devices, retail digital signage management.

As mentioned above, a variety of application services based on M2M communication which has great potential are being supported in combination with many wired and wireless network. In response to this trend, standardization activities related to M2M communication are proceeding briskly in many organizations. In IEEE, especially, a project is underway to support M2M communication in cellular network based on IEEE 802.16 technology[1][2][3].

One of the main issues for M2M communication based on cellular network such as IEEE 802.16 is the large number of devices in service coverage and concurrent network access attempt from these devices. In cellular network, contention-based random access scheme which is called 'ranging' is used for network entry. Ranging is based on slotted-ALOHA method. The MS(Mobile Station) in a cell send the ranging preamble through the designated ranging resource and try to

access to network through the competition. At that time, ranging resources to transmit the ranging preamble is called 'ranging channel' or 'ranging opportunity'. One ranging channel or opportunity is the unit of a slot in slotted-ALOHA. Also, EB(Exponential Backoff) method and multiple orthogonal codes or pseudo-random sequences are used for contention resolution and enhancement of efficiency of the ranging resource.

It is necessary to set proper ranging parameters and predict ranging resources which are needed to distribute concurrent network access attempt from many devices and meet requirement of M2M application service.

In this work, we suggest analytical model of random access performance for M2M communication on cellular network based on previous studies about performance analysis of slotted-ALOHA and EB. Also we verify the applicability of our analytical model and conduct performance evaluation of random access for M2M communication on IEEE 802.16 network through computer simulation. We can select the proper ranging parameters to enhance efficiency of limited ranging resource and reduce network access delay based on our performance evaluation results.

II. SYSTEM MODEL

Figure 1. represents initial network entry procedure on IEEE 802.16 network. In IEEE 802.16 network, MS conduct network entry and UL(Uplink) synchronization through the ranging. The MS which want to access the network should acquire ranging resource allocation information and ranging parameters such as number of ranging code, backoff window size and maximum number of ranging retries through broadcasted message. The MS which complete acquisition of essential information for ranging transmit ranging preamble code in an arbitrary slot randomly selected within initial backoff window. At that time, ranging preamble code should be also randomly selected within pre-determined ranging preamble code domain. And then, the MS waits ranging acknowledge message from BS(Base Station). If ranging preamble code is not successfully decoded by BS, MS repeat the procedure after increasing the backoff window size twice. If MS does not receive ranging acknowledge message even after maximum retransmission, MS should restart the ranging procedure with initial ranging parameters. If ranging preamble code is successfully decoded by BS, BS inform success of ranging to MS and can command adjustment of timing offset,

frequency offset and transmit power for UL synchronization. After completion of UL synchronization, BS allocates UL resource to MS for ranging request of MS. And then, network entry procedure would be finished after negotiation, authorization and registration.

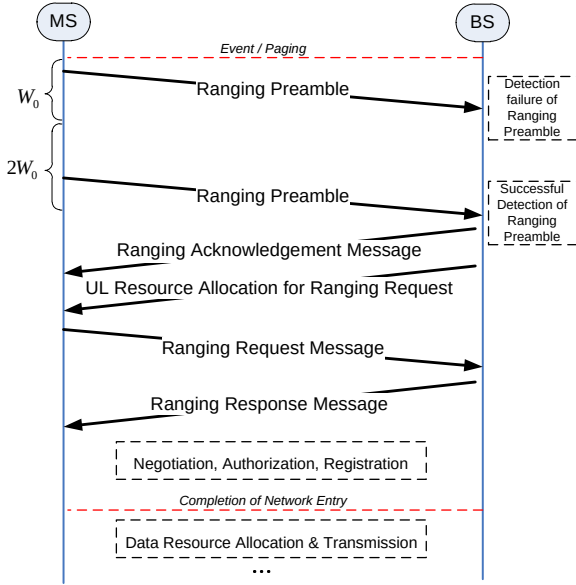


Figure 1. Initial network entry procedure on IEEE 802.16 network

Network entry type can be classified into two categories, i.e. device-initiated network entry by occurrence of access event and network-initiated network entry by paging. If MS have different paging offset for each other, we can specify frequency of network access attempt as the packet arrival rate independent of network entry type. In general, it is known that number of arrival packets for a period of time follows Poisson distribution.

III. PERFORMANCE OF RANDOM ACCESS

A. Slotted-ALOHA

Slotted-ALOHA[4] is widely used protocol for random access due to the simplicity despite low slot efficiency and rapid growth of collision in proportion to the number of node. Slot efficiency η of slotted-ALOHA method can be obtained as follows

$$\eta = {}_N C_1 p (1-p)^{N-1} = Np(1-p)^{N-1} \quad (1)$$

where p is the probability that a node will transmit in an arbitrary slot and N is the number of node. If p is $1/N$, the slot efficiency is maximized. Figure 2. shows the slot efficiency for the number of node and p . As increasing N , η can be given by

$$\lim_{N \rightarrow \infty} Np(1-p)^{N-1} = Ge^{-G} \quad (2)$$

where G is the offered load in terms of network and defined as $N \times p$. Figure 3. shows the slot efficiency in case of large N . When G is 1, the slot efficiency reach the maximum, i.e. approximately 37%.

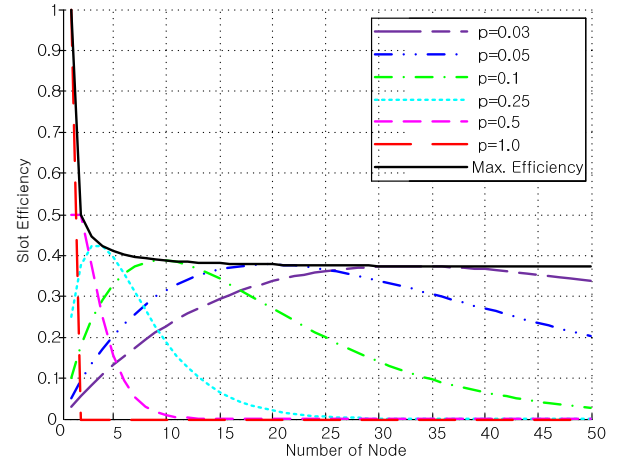


Figure 2. Slot Efficiency of Slotted-ALOHA

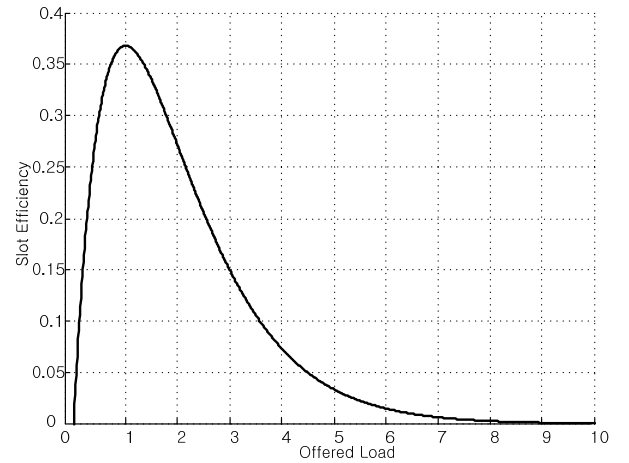


Figure 3. Slot Efficiency of Slotted-ALOHA for Large N

B. EB (Exponential Backoff)

As increasing offered load, collision is also rapidly increased in Slotted-ALOHA method as we can see from figure 3. Therefore collision resolution method should be applied to resolve the problem. EB method is the efficient solution of the problem. In EB method, the node selects an arbitrary slot for transmission within initial backoff window. If collision occurs, the node increases the backoff window size twice for next transmission. Backoff window size is $r^i W_0$ at i -th retransmission, where r and W_0 are the backoff factor and initial backoff window size, respectively. Also, the unit of the backoff window size is the slot. Especially, we call the case of $r = 2$ BEB (Binary EB).

Exact analysis of EB is very complicated but a study have been conducted for the performance of EB in terms of network load[5]. In [5], mean access delay and slot efficiency are analysed in steady-state assuming the fixed number of nodes.

Figure 4. represents state transition diagram of EB in saturated condition. Node would be in i -th state after i times failure of transmission.

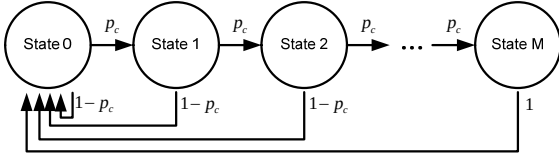


Figure 4. State Transition Diagram of EB

Let p_t and p_c be the probability that a node will transmit and collision will be occurred in an arbitrary slot, respectively, then p_t and p_c obtained by follows

$$p_t = \frac{2}{W_0 \sum_{i=0}^M (r p_c)^i / \sum_{i=0}^M p_c^i + 1} \quad (3)$$

and

$$p_c = 1 - (1 - p_t)^{N-1} \quad (4)$$

where $i = 0, 1, 2, \dots, M$ and M is the number of maximum retransmission. Solving (4) for p_t , p_t can be also expressed by p_c and N as follows

$$p_t = 1 - (1 - p_c)^{1/(N-1)} \quad (5)$$

We can find a unique solution by numerical method for intersection (3) and (5) in range of $0 \leq p_c \leq 1$, because of equation (3) is the monotonically increasing function, equation (5) is the monotonically decreasing function and both are the continuous function in range of $0 \leq p_c \leq 1$.

Thus, we can calculate the slot efficiency by using equation (1) and p_t obtained by numerical method. Also, mean access delay which defined as the time from the moment a node starts the access attempt to moment the access is succeeded can be obtained by using the expected total number of backoff time slots. Mean access delay is obtained by follows

$$\bar{D} = \frac{1}{2} \left\{ \frac{1}{1 - p_c} - \frac{(M+1) p_c^{M+1}}{1 - p_c^{M+1}} + \frac{W_0}{1-r} \left(1 - \frac{r(1-p_c)}{1-p_c^{M+1}} \sum_{n=0}^M (r p_c)^n \right) \right\} \quad (6)$$

Figure 5. and figure 6. show slot efficiency and mean access delay for initial backoff window size W_0 and number of nodes N in case of BEB with $M = 4$.

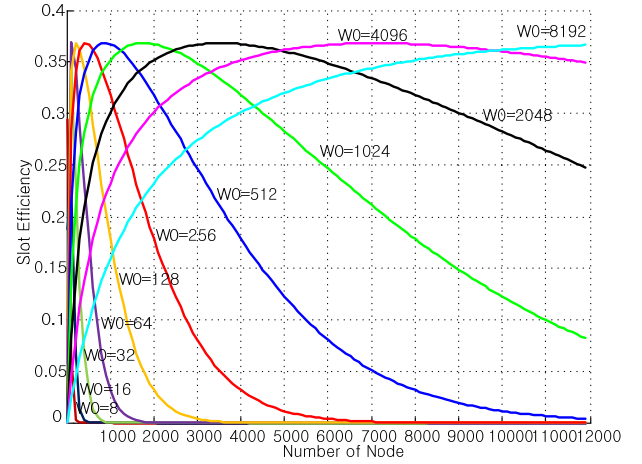


Figure 5. Slot Efficiency of BEB with M=4

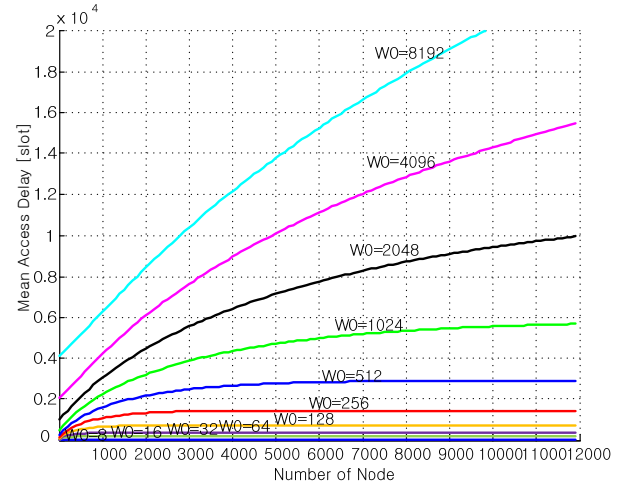


Figure 6. Mean Access Delay of BEB with M=4

Large initial backoff window size lead to a large increase in mean access delay but if we select too small window size compare to number of node, the slot efficiency is degraded rapidly. It means that most of nodes will continue to fail in their access attempt.

C. Analytical Model of Random Access Performance for M2M communication on Cellular Network

In this section, we suggest analytical model of random access performance for M2M communication on cellular network based on performance analysis results of slotted-ALOHA and EB. Figure 7. shows a simplified random access model on cellular network.

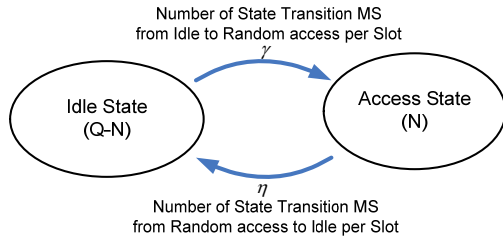


Figure 7. Random Access Model for Cellular Network

We assume that the number of MS is finite in service coverage. Let γ be the number of MS whose state is changed from idle to access state per slot. Then γ can be given by

$$\gamma = (Q - N) \times R \quad (7)$$

where Q , N and R are the total number of MS, the number of MS in access state and packet arrival rate per slot, respectively. If we assume saturated condition, following relation is established between γ given by (7) and η obtained by (1) (3) and (5).

$$(Q - N) R = \eta \quad (8)$$

Thus, we can find the relation between N and R by numerical method if we know Q . Figure 8. shows the relation between N and R in case of $Q = 12000$ for various initial backoff window size.

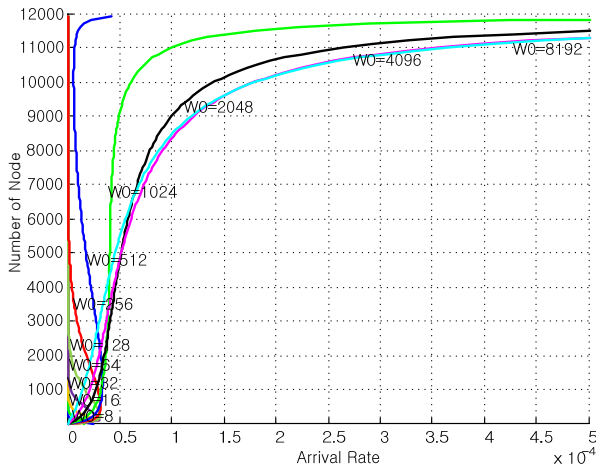


Figure 8. Relation between N and R in case of $Q=12000$

Also we can numerically calculate the slot efficiency and mean access delay by using the relation between R and N . Figure 9. and figure 10. show the slot efficiency and mean access delay for R in model of figure 7. The markers indicate the simulation results.

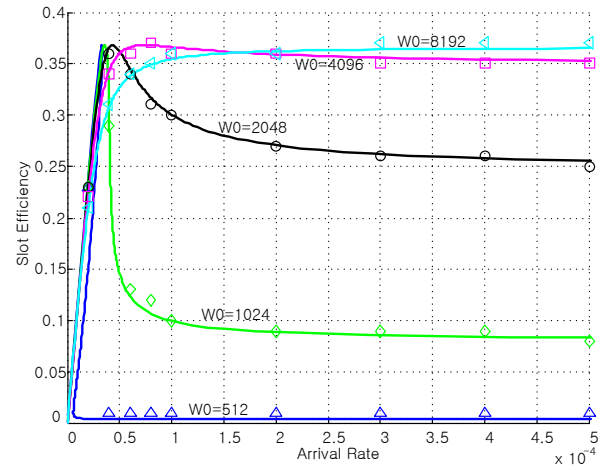


Figure 9. Slot Efficiency on Cellular Network

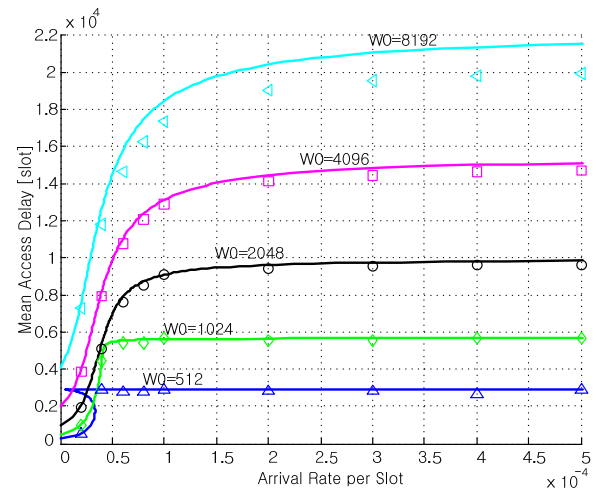


Figure 10. Mean Access Delay on Cellular Network

Simulation results are matched with analytical model for wide range of W_0 and R in case of high network load i.e. Q is sufficiently large such as M2M communication on cellular network.

When W_0 is 8192, a little difference are observed. But the difference results from limitation of maximum backoff window size. We restricted the maximum backoff window size to 65536 according to IEEE 802.16 standardization. Thus backoff window size is not 131072 but 65536 at 4th retransmission like 3rd retransmission.

When W_0 is below 256, most of the node fail the network access and slot efficiency is almost zero. There is no MS which succeed in access attempt in our simulation, so we cannot calculate the mean access delay.

IV. PERFORMANCE EVALUATION OF RANDOM ACCESS FOR M2M COMMUNICATION ON IEEE 802.16 NETWORK

In this section, we conduct the practical performance evaluation for M2M communication by applying ranging

parameters of IEEE 802.16 network. Table 1. shows the simulation parameters and assumption. M2M communication environment is referenced by [6].

TABLE 1. SIMULATION PARAMETERS AND ASSUMPTION

Parameters	Value
Total Number of MS	12000
Packet Arrival Rate per Slot	[0.0001;0.0005]
Distribution of Arrival Packet	Poisson
Initial Backoff Window Size	[16;32;64;128;256]
Number of Ranging Channel per Frame	1
Number of Ranging preamble code per channel	32
Maximum Number of Retransmission	4
Frame Duration	5ms
Detection Probability of Ranging Preamble Code.	99%
Error Probability of Message	0%

Number of ranging channel in a frame reduces slot interval, so practical slot interval is calculated by frame duration divided by number of ranging channel per frame. Also, number of ranging preamble code in a ranging channel changes effective initial backoff window size. Effective initial backoff window size can be calculated by product of intial backoff window size and number of ranging preamble code per ranging channel.

Figure 11. and Figure 12. show slot efficiency and mean access delay for M2M communication on IEEE 802.16 network.

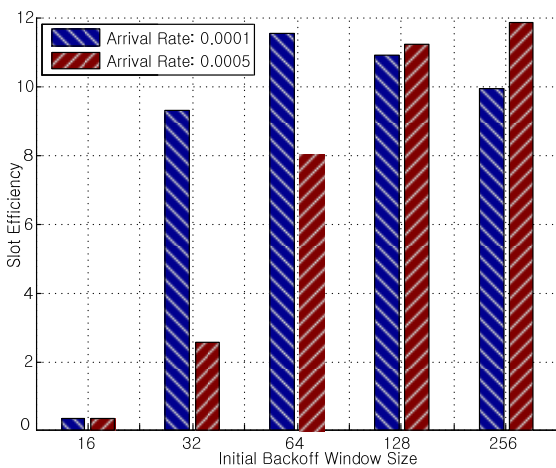


Figure 11. Slot Efficiency on IEEE 802.16 Network

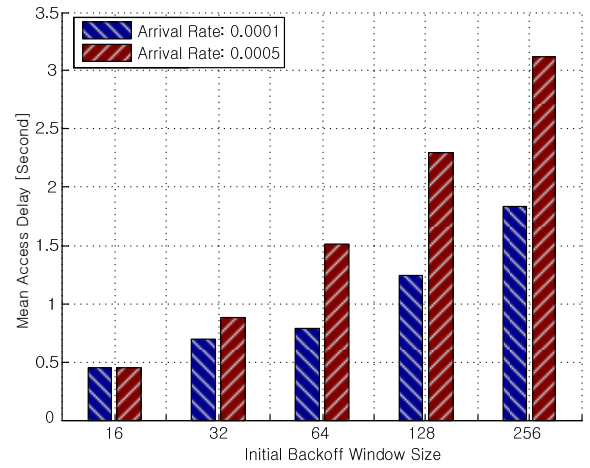


Figure 12. Mean Access Delay on IEEE 802.16 Network

In addition, variance of the access delay and probability of drop are also important performance metrics. It can be evaluated by CDF(Cumulative Density Function) of access delay. Figure 13. and 14. show the access delay CDF.

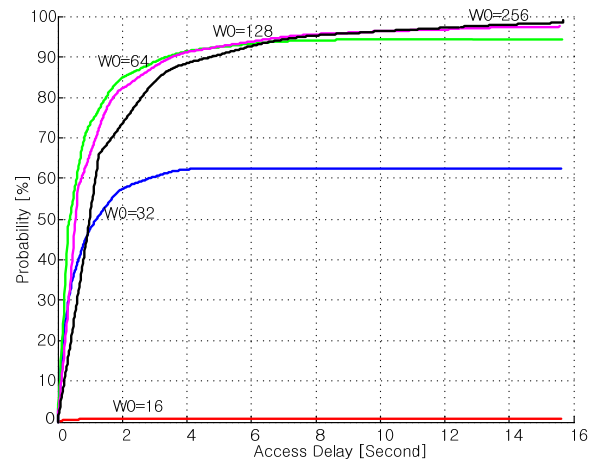


Figure 13. CDF of Access Delay in case of R=0.0001

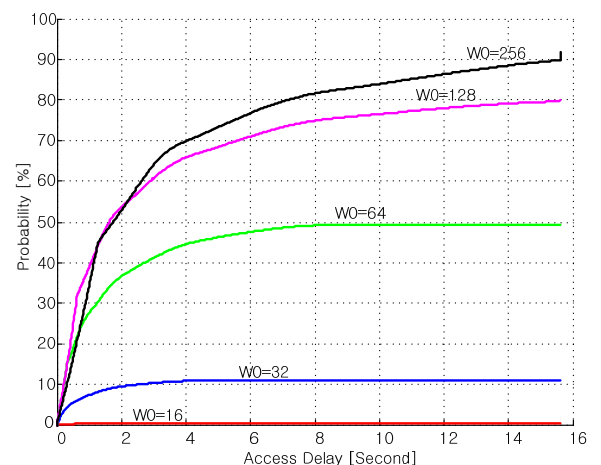


Figure 14. CDF of Access Delay in case of R=0.0005

If we want to maximize efficiency of ranging resource, we should select initial backoff window size of 64 and 256 in case of $R = 0.0001$ and $R = 0.0005$, respectively, as we can see figure 11. In that case, approximately 12 MS succeed in network access per slot. But the large initial backoff window size lead to increment of mean access delay as we can see figure 12.

Also, if we want to maintain the probability of less than 50% in failure of access attempt, we can select initial backoff window size of 32 and 64 to minimize mean access delay in case of $R = 0.0001$ and $R = 0.0005$, respectively, as we can see figure 13. and figure 14. In that case, it takes approximately 1 second and 8 seconds to reach the probability of 50% in success of access attempt. To reduce the delay, we should allocation more ranging resource.

When there are extremely lager number of MS in service coverage, it is inescapable that access delay increase. But we can maximize the efficiency of ranging resource and minimized the access delay through the selection of proper ranging parameters and amount of ranging resource based on the result of random access performance evaluation for M2M communication on IEEE 802.16 network.

V. CONCLUSIONS

In this paper, we suggest analytical model of random access performance for M2M communication on cellular network.

Also we verify the applicability of our analytical model and conduct performance evaluation of random access performance for M2M communication on IEEE 802.16 network through computer simulation. The evaluation result can be helpful to select proper ranging parameters and required ranging resource to meet service requirement.

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