Prioritized Access for Emergency Stations in Next Generation Broadband Wireless Networks

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Abstract

We focus on the interference between mobile stations as they attempt to gain access to an OFDMA-based WiMAX/IEEE 802.16 network. We propose a set of strategies that enable base stations to 1) reduce or eliminate the interference between emergency and non-emergency mobile stations and 2) provide prioritized access to emergency mobile stations. Our strategies include introducing a sliding contention window, redistribution of ranging codes and the ability of base stations to delay the entry process of any mobile station. We give an analysis of our strategies and some simulated results.

1. Introduction

Historically, wireless communications for emergency services predate the modern cellular network by almost fifty years. The first one-way police radios were introduced by the Detroit Police Department in 1928. The first two-way systems were introduced in New Jersey in 1933 [10]. Since this time, dedicated emergency communication systems have been developed separate from the more modern cellular networks. With the recent introduction of packet-based next generation broadband wireless networks supporting a wide variety of applications, such as WiMAX/802.16, it is time to investigate the integration of emergency communication systems with public networks.

Various standardization bodies [3, 6] define the four following kinds of emergency communications. *Citizen to authority* describes the citizen's communication with the authorities such as placing a 911 call. *Authority to citizen* is the authority's communication with citizens, such as an early warning system. *Authority to authority* is the authorities' ability to communicate amongst themselves, including between different agencies. Finally, *citizen to citizen* is the citizens' ability to communicate with family and friends in a time of crisis.

When emergency situations arise, wireless cellular networks can be overloaded with huge increases in the number of users attempting to gain access. In [15], the authors indicate that during an emergency situation the network can experience as much as a tenfold increase over normal network demand. This can lead to life-threatening conditions if authorized emergency users cannot maintain service with the network.

In Orthogonal Frequency Division Multiple Access (OFDMA) based mobile WiMAX/802.16 networks [1], the network entry process begins with a mobile station (MS) sending a random Code Division Multiple Access (CDMA) ranging code during a contention period after synchronizing with a base station (BS). This process is anonymous, meaning the BS must process all ranging requests in order to determine if an MS can be granted entry.

The motivation of this work is twofold. First, we attempt to reduce or eliminate the interference between emergency and non-emergency MSs during the CDMA initial ranging contention period. Second, we attempt to have the BS process ranging requests from emergency MSs (EMSs) ahead of non-emergency MSs wherever possible. This requires the ability to distinguish between emergency and non-emergency MSs. We study a single uplink channel in use by a WiMAX/802.16 BS.

1.1. Results of the Paper

We propose strategies that enable BSs in an OFDMA based WiMAX/802.16 network to provide prioritized network entry access to an emergency class of MSs. Our proposed strategies are designed to reduce or eliminate the interference between emergency and non-emergency MSs during the contention-based CDMA initial ranging process. They can also let the BS determine the type of MS attempting initial ranging and gives the BS flexibility on controlling which MSs are permitted to continue the network entry process even before the actual ID of the MSs are known. We evaluate the performance of our strategies through a series of simulations of the CDMA ranging operation when a BS is hit by a sudden burst of MS ranging messages.

The remainder of the paper is organized as follows. In Section 2, we give a background to the problem and review some previous work. In Section 3, we introduce our proposed strategies for prioritizing access to EMSs. In Section 4, we analyze the potential collisions between MSs during the CDMA initial ranging process. We provide a description of the simulation environment along with the simulation results in Section 5. Finally, we discuss ongoing work and conclude in Section 6.

2. Background

Initial ranging is an important step in the WiMAX/802.16 network entry process. It is used by an MS to determine the transmit power and timing offsets, in order to synchronize transmissions, to gain access to the network via a BS.

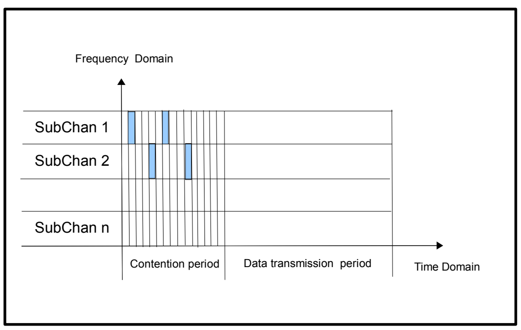

Figure 1. Contention and data period of an OFDMA frame.

In OFDMA based WiMAX/802.16, an MS must first synchronize with the downlink (DL) and uplink (UL) via the DL-MAP and UL-MAP messages. From the UL-MAP, an MS obtains the ranging opportunities in terms of the number of contention slots in the next frame as well as the CDMA codes to be used. Figure 1 shows the contention and data transmission periods of an OFDMA frame. The contention periods are structured into contention slots. One or more groups of six subchannels are allocated for the ranging process. The CDMA codes are a set of special pseudonoise (PN) 144-bit numbers. There are 256 codes available divided into the following types, initial ranging, periodic ranging, handover ranging and bandwidth requests.

The MS randomly chooses a ranging slot within its initial contention window and a PN CDMA ranging code that it transmits twice in two consecutive contention slots. When the MS sends a ranging request, it sets a timer (T3). When T3 expires and the MS has not heard a response from the BS it assumes its request was lost or not heard. The MS then enters a backoff phase, doubling its initial contention window size and selecting a random opportunity within its new contention window. This process repeats until the MS hears a response from the BS or a maximum number of retries has been reached.

The BS responds to the MS in a downlink frame using the CDMA code sent by the MS indicating on which contention slot the message was received to identify the MS. Since the MS only sends a random CDMA code, the BS has no knowledge of whether the MS is an emergency or non-emergency station. This causes problems, since there is no way to prioritize access to stations until further in the network entry process of establishing a connection with the BS. This leads to emergency and non-emergency stations interfering with and competing on the same contention slot/code pairs.

2.1 Related Work

The 3rd Generation Partnership Project (3GPP) work in [2] states that while investigation is underway to provide standardized Priority Service for emergency responders in circuit switched speech communications, there is a need to undertake this effort for packet-based (e.g. IP) networks. The IEEE 802 group has also recently released a *Call for Interest* [12] on creating a study group for emergency service provisioning.

There have been a number of works on priority service for 3G cellular networks including priority access schemes in [9], a common packet channel access scheme [11] and a priority stack random access scheme for Wideband Code Division Multiple Access (W-CDMA) [7].

The authors in [13] propose providing high and low priority levels of service in WiFi/IEEE 802.11 networks by dividing the contention window in half. They determined an overlap function to allow low priority traffic to contend on a portion of the high priority contention zone when traffic load is light. WiFi/802.11 networks typically deal with smaller numbers of users.

Public Use Reservation with Queuing All Calls (PURQ-AC) [15] has been proposed where separate buffers are maintained for emergency and public incoming calls. The buffers are served in a round-robin fashion with the emergency buffer given one fourth of the allocation. The authors in [8, 16] look at prioritizing emergency calls through preemption or delay of public calls. Their focus is on analyzing the load on the system while prioritizing emergency traffic and minimizing disruption to the non-emergency traffic.

Radio resources are limited and must be allocated in an efficient manner to ensure QoS requirements are met. It was seen in the aftermath of the attacks of September 11, 2001, that the cellular networks were overwhelmed by too many users trying to access the network. In the context of emergency communications, there is a need to find a way to avoid the interference from too many users. Admission control must be applied in order to limit the number of devices connected to the network. At times, we must provide prioritized entry to the network to emergency users. New adaptive access control schemes are required.

Most previous work focuses on the prioritizing of MS traffic within the system once a MS has communicated with a BS. We propose strategies to provide prioritized emergency access by reducing or eliminating the interference between emergency and non-emergency MSs during the WiMAX CDMA initial ranging process with a BS as well as attempting to process emergency ranging requests ahead of non-emergency requests whenever possible. One drawback of the anonymous CDMA ranging process is that since the IDs of MSs are unknown the BS must process all ranging requests equally.

3. Proposed Strategies for Prioritized Emergency Access

We propose a set of strategies for prioritizing emergency access to an OFDMA based mobile WiMAX/802.16 network. We envision a collaborative system where neighboring BSs coordinate on-the-fly to best serve the set of MSs attempting to gain access to the network. The BSs can adjust system parameters to meet real-time network conditions. BSs implement strategies such as adjusting the contention window for EMSs, advertise special emergency CDMA ranging codes or delay sending range response messages to non-emergency MSs.

Initially, a BS advertises a single set of contention opportunities for initial ranging. The BSs treats all MSs as equals with no special prioritization. As the BSs detect events occurring in various locations in the network, the strategies are applied locally or globally and can be adjusted to best handle the changing situation on the ground. This facilitates providing a priority to EMSs network access. The detection of events impacting the network are beyond the scope of this initial work.

In the following sections, we introduce our strategies used by the BSs in order to facilitate the emergency prioritized access including the use of a sliding emergency contention window, a new class of CDMA ranging codes and allowing BSs to delay responses to non-emergency MSs for a portion of their ranging timeout.

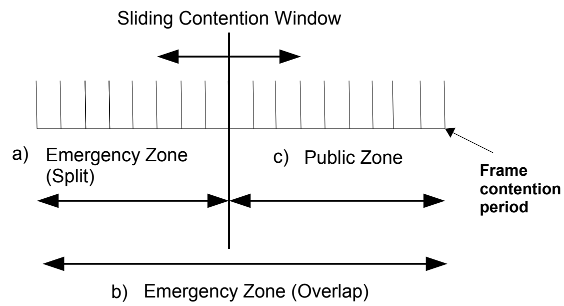

Figure 2. Split and overlapping contention windows for emergency and public MSs.

3.1. Emergency Contention Zone

Our first strategy is to provide a dedicated portion of the ranging contention period to EMSs. This can be done in various ways. The first is to divide the ranging contention period into separate windows, one for EMSs and one for non-emergency MSs. The second way is to extend the first idea by splitting the contention period into separate windows, but allowing the EMSs to utilize all slots within the contention period while limiting the non-emergency MSs to a subset of slots. Figure 2 depicts the contention period available and the sliding contention window to break up the contention period into emergency and public zones. Alternately, whole ranging contention periods for one frame or multiple sequential frames can be allocated to EMSs, thus delaying the contention of non-emergency MSs.

In order for MSs to determine when they can perform ranging, WiMAX/ 802.16 BSs advertise the initial ranging contention period with the CDMA Initial Ranging Information Element (IE) of the DL-MAP. To support the split contention window, we introduce a new CDMA Emergency Ranging IE message. This Emergency_Ranging_IE message informs EMSs of the dedicated emergency ranging slots allocated by the BS during the next frame.

With the first and third strategies, a BS can know the number of EMSs attempting to enter the network by monitoring the emergency ranging contention slots. With the second strategy, the total number of EMSs cannot be known since MSs pick a random CDMA code from the pool of available codes. Only the EMSs that transmit their CDMA code during the emergency contention window are known since the process is anonymous. We address the anonymous CDMA codes in the following section.

The size of the emergency contention zone is determined by some threshold of emergency events such as the number of EMSs currently connected to the BS or the arrival rate

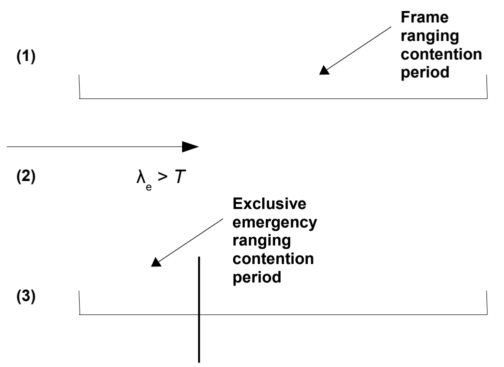

Figure 3. Threshold of arrivals of EMS ranging attempts and emergency contention zone.

of initial ranging messages from EMSs. Figure 3 shows the process of determining the size of the emergency contention zone. Initially, a BS advertises a single contention period available for ranging. This is depicted in Figure 3 (1). As the arrival rate of emergency range requests, λ_e crosses a threshold T, as shown in Figure 3 (2), it triggers the BS to determine an exclusive contention period for emergency ranging in future frames as shown in Figure 3 (3). As an alternative, the BS can use a threshold of the number of EMSs currently connected to make this decision.

By setting the emergency zone to 100% of the contention region and not advertising public initial ranging, each BS can revert to an emergency only mode and knows that all range requests received are from EMSs.

3.2. Emergency CDMA Ranging Codes

WiMAX/802.16 defines a series of CDMA codes to be used for ranging. The MS randomly chooses one of the codes and sends it during a random ranging contention slot. If the BS hears the code, it sends a reply to the MS with the code and slot used. This is an anonymous process since the code used is not related to the ID of any particular MS.

In order to break this anonymity at the BS, we introduce a new emergency category of CDMA ranging code. By introducing a new type of ranging code, the BS can determine which MSs are emergency stations and should be given a higher priority. A portion of the total number of ranging codes are designated for EMSs only. Now, the BS can determine exactly which MSs are emergency devices, although not their IDs, and make decisions accordingly. The BS determines the breakdown on the number of codes to assign to emergency and non-emergency MSs based on the changing conditions of the network in a similar way as for determining the size of the emergency contention zones.

3.3. Base Station Delayed Response

Once a BS has the ability to distinguish between non-emergency and EMSs, either through non-overlapping contention zones or the use of special CDMA codes, it can use this knowledge to make further decisions regarding MSs that are performing initial ranging.

When an MS sends its CDMA ranging code it sets the T3 timer, which is 60 ms by default. We propose that a BS, under conditions of stress due to the presence of EMSs, delays responses to any non-emergency MS for a portion of the T3 timer value while waiting to see if any new emergency MSs initial ranging requests arrive. This delay can be determined in a similar manner as for setting the size of the emergency contention zone and the number emergency CDMA codes.

4. Analysis of Mobile Station Collisions

We present our analysis of the collision model to calculate the expected number of collisions between MSs in the overlapping contention zones as described in Section 3.1. We have the following parameters. Let s be the number of contention slots during the ranging period and c be the number of assigned CDMA ranging codes. S is the number of slot/code ($s \times c$) pairs. n is the number of MSs and r is the number of MSs that select a given slot/code pair.

Given that we have s contention slots and c CDMA codes, the probability that a given MS selects a given slot/code pair is denoted by

$$\frac{1}{(s \times c)} = \frac{1}{S}$$

Since we are looking to examine the number of collisions this is further expanded to determine the probability that a given set of r out of n MSs select the same slot/code pair as

$$\left(\frac{1}{S}\right)^r \left(1 - \frac{1}{S}\right)^{n-r}$$

From this, we can calculate the probability that *any* set of r MSs select the same slot/code pair as

$$\binom{n}{r} \left(\frac{1}{S}\right)^r \left(1 - \frac{1}{S}\right)^{n-r}$$

Continuing, calculate the expected number of slot/code pairs having a collision of r users as

$$S\binom{n}{r}\left(\frac{1}{S}\right)^r\left(1-\frac{1}{S}\right)^{n-r}$$

Then, we calculate the expected number of collided users across all slot/code pairs for a given value of r as

$$rS\binom{n}{r}\left(\frac{1}{S}\right)^r\left(1-\frac{1}{S}\right)^{n-r}$$

Finally, we can obtain the expected number of collided users across all slot/code pairs when $r > 1$ (there is a collision when more than one MS select a given slot/code pair) as

$$\sum_{r=2}^{n} rS\binom{n}{r}\left(\frac{1}{S}\right)^r\left(1-\frac{1}{S}\right)^{n-r} \quad (1)$$

Figure 4 shows the expected number of collided users in the overlapping region of the contention period for the WiMAX default operation as well as with a dedicated emergency contention window (CW) covering 25%, 50% and 75% of the contention period. The calculations are made using Equation 1 for 10/25, 25/50, 50/75 and 50/100 (emergency/non-emergency) MSs attempting ranging on a single frame with 16 contention periods and 128 CDMA ranging codes.

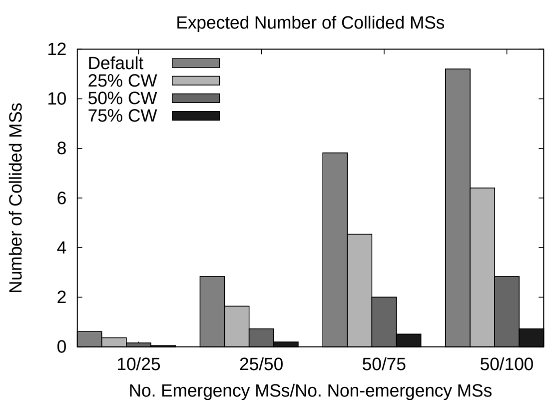

Figure 4. Expected number of MSs involved in collisions within overlapping contention window.

5. Performance Evaluation

We developed a series of simulations to examine the performance of the CDMA ranging operation when a BS is hit by a sudden burst of MS ranging arrivals. We model the contention ranging process on a single frequency in use at a BS. An MS sends its randomly chosen CDMA ranging code over two consecutive ranging opportunities. If a BS hears an MS's request, this does not determine that it will be granted access. If the number of MSs attempting to gain access to the network resources is greater than the number that can be accommodated, then some MSs will not be granted access. The goal of the system is to provide for prioritized emergency access. We want to reduce, or eliminate interference between emergency and non-emergency MSs and to enable the BSs to process requests from emergency MSs ahead of those from non-emergency MSs.

Table 1 shows the simulation parameters tested. We conducted a series of simulations with a combination of emergency and non-emergency MSs competing for network access during the ranging contention period. In each simulation, the number of MSs arriving during each frame for five consecutive frames were varied from 10-50 and 25-100 for emergency and non-emergency MSs respectively. The initial contention window backoff was set to 16 slots for all MSs and there were 16 ranging opportunities in each frame. The size of the emergency contention zone was varied between 0% and 75% of the total number of opportunities. A total of 128 CDMA codes were assigned for initial ranging. For each set of fixed parameters, the simulation was run for a series of 1000 trials and results taken. We measured two important metrics: (1) the probability of collisions between emergency and non-emergency (where possible) and (2) order of processing of MSs by the BS. All results were calculated with a 95% level of confidence.

Simulation Parameters	
Number of EMSs per frame	10-50
Number of Non-emergency MSs per frame	25-100
Initial Contention Window Size	16
Ranging Opportunities per Frame	16
Emergency Zone Size (%)	0%-75%
Number of CDMA Ranging Codes	128
Emergency Codes (%)	0%-75%
Frame Length	5ms
Default T3 Timer	60ms
BS Delayed Response	10-30ms

Table 1. Simulation parameters.

5.1. Emergency Contention Zone

In the first scenario, we tested the emergency contention zone as described in Figure 2 a) where emergency MSs are given a portion of the contention ranging opportunities for their exclusive use. This has the advantage that there is no chance of a collision between emergency and non-emergency MSs. However, the potential drawback is that if the emergency contention zone is too small in comparison to the initial contention window of the MS, the MS may be forced to wait a number of frames before sending it's CDMA code.

The results are shown in Figure 5. In order to evaluate our strategies we observe the percentage of EMSs that are processed by the BS within the first half of all MSs attempting ranging. The figure shows the results for the WiMAX default, 25%, 50% and 75% dedicated emergency contention zone scenarios. Here we see that a separate contention window performs ahead of WiMAX default for and emergency contention zone of 50% and 75%, but not as well for the case of 25%. For the WiMAX default case, we see results of 49.4% to 49.6% of emergency MSs processed within the first 50% of all MSs. Similarly, we see between 40.05% to 41.98%, 57.60% to 62.65% and 71.24% to 75.84% of EMSs processed for a separate emergency contention window of 25%, 50% and 75% respectively. The results are summarized in Table 2

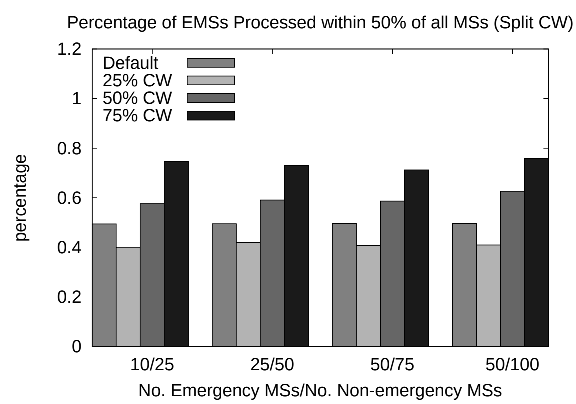

Figure 5. Percentage of EMSs processed in the first 50% of all MSs with split contention window.

% of Emergency MSs Processed	
WiMAX Default	49.44% to 49.61%
25% Emergency CW	40.05% to 41.98%
50% Emergency CW	57.60% to 62.65%
75% Emergency CW	71.24% to 75.84%

Table 2. Percentage of EMSs processed within 50% of all MSs with split contention window.

The next scenario tested is an extension of the exclusive emergency contention zone. As shown in Figure 2 b), the BS assigns a portion of the contention slots to the exclusive use of EMSs, but EMSs can contend on any of the contention slots advertised in the frame. This gives a portion of non-interfering emergency slots and an overlapping contention period where both types of MSs contend.

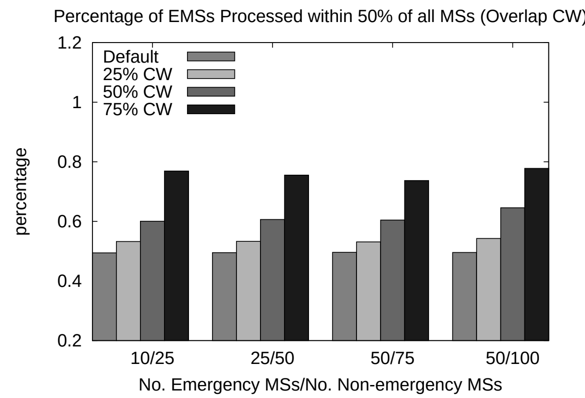

Figure 6. Percentage of EMSs processed in the first 50% of all MSs with overlapping contention window.

The results are shown in Figure 6 where we see further improvements over separate contention zones to 53.12% to 54.28%, 60.06% to 64.58% and 73.72% to 77.80% of EMSs processed for the overlapping contention windows with dedicated emergency contention zones of 25%, 50% and 75% respectively. The results are summarized in Table 3.

% of Emergency MSs Processed	
WiMAX Default	49.44% to 49.61%
25% Emergency CW	53.12% to 54.28%
50% Emergency CW	60.06% to 64.58%
75% Emergency CW	73.72% to 77.80%

Table 3. Percentage of EMSs processed within 50% of all MSs with overlapping contention window.

Both graphs in Figure 7 compare the percentage of emergency/non-emergency MS collisions between the WiMAX default setting versus when the BS sets the dedicated emergency contention zone to 25%, 50% and 75%, but allows EMSs to contend across all contention slots. The upper graph shows the simulation for a single frame of contention, where all MSs arrive at once. This shows a similar result to the expected as shown in Figure 4. The lower graph shows the same measurement with the standard multiple frame arrivals. In both cases, we can see that the probability of collisions between emergency and non-emergency MSs can be greatly reduced simply by reserving a portion of the contention period for emergency use.

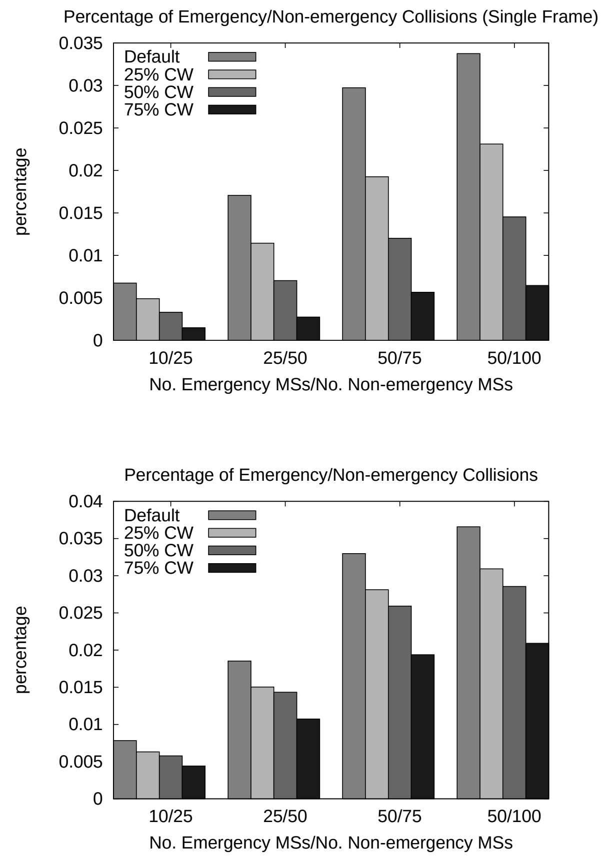

Figure 7. Probability of MS collisions, overlapping contention window.

5.2. Emergency CDMA Ranging Codes

In our simulations, the use of CDMA ranging codes does not have a major impact in the percentage of EMSs processed before non-emergency MSs. The exception is in extreme cases where with a large emergency contention window size, large number of emergency CDMA codes along with a large MSs arrivals lead to a greater than 30% collision rate among non-emergency MSs. The main use of emergency CDMA codes is that they are required in order to distinguish between emergency and non-emergency MSs when they have overlapping contention periods. One benefit of increasing the number of emergency CDMA codes is that we saw a reduction in the number of collisions among EMSs.

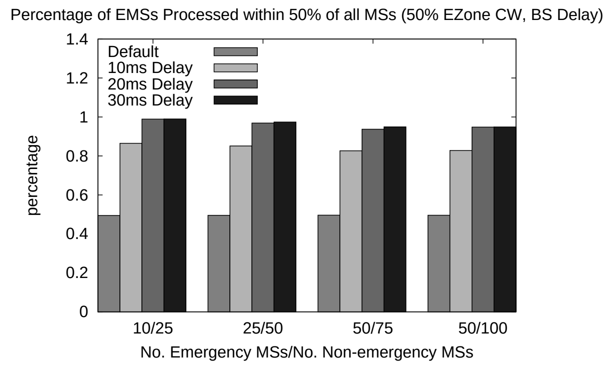

Figure 8. Percentage of EMSs processed in the first 50% of all MSs with split contention windows and BS delay.

5.3. Base Station Delayed Response

In our final set of experiments, we investigated the effect of introducing a delay by a BS when sending a response to non-emergency MSs. The delay is for a portion of the default ranging timeout, T3, while the BS is waiting to hear from possibly more EMSs. In Figure 8, we present the results for introducing a BS delay of 10, 20 and 30 ms with a 50% separate emergency contention zone. Here we see that a delay of only 20 ms increases the percentage of EMSs processed within 50% of all MSs to the range of 93.70% to 98.91%.

6. Conclusions and Future Work

We have proposed strategies that can enable BSs in a WiMAX/802.16 network to provide prioritized network entry access to an emergency class of MSs. Our proposed strategies reduce or eliminate the interference between emergency and non-emergency MSs during the contention-based CDMA initial ranging process. They can also let the BS determine the type of MS attempting initial ranging and gives the BS flexibility on controlling which MSs are permitted to continue the network entry process even before the actual ID of the MSs are known.

With the introduction of emergency contention zones we increased the percentage of EMSs range requests processed by between 24% to 53% when compared to the WiMAX/802.16 default. These percentages are increased to between 70% and 94% over default WiMAX/802.16 with a 50% emergency contention zone and a BS delayed range response to non-emergency MSs of 10 ms and 20 ms respectively.

The implementation of our strategies is flexible. BSs can operate from WiMAX default mode, where all MSs have equal access, through to total emergency mode where only EMSs attempt the network entry process. In times of high emergency demand, or disaster, our proposed strategies can be tuned to only grant access to EMSs. The strategies presented can also be applied to other contention regions such as those for periodic ranging and bandwidth requests.

Continuing work includes a more extensive simulation to provide for the on-the-fly tweaking of our proposed strategies to determine thresholds for the setting of emergency contention zone sizes, emergency CDMA codes assigned and timings of BS delays. This would allow the BSs to adjust to the real-time network conditions. Larger scale evaluation should be done including multiple channels per BS as well as having multiple collaborating BSs in order to determine how to best handle the arrival of an explosive number of EMSs as emergency situations arise. It should be investigated how other ranging types as well as bandwidth requests from EMSs can benefit from similar strategies. Additional future work includes investigating the the WiMAX/802.16 Quality of Service (QoS) structure in order to better understand and support the QoS requirements of emergency applications as they compete with non-emergency applications with similar QoS demands.

7 Acknowledgements

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