CHAPTER 6

ADAPTIVE INITIAL/MAXIMUM BACKOFF-WINDOW-SIZE FOR IEEE 802.16 BASE STATIONS

From Chapter 5, it is clear that the ARQ parameter, \( ARQ\_RETRY\_TIMEOUT \) must be properly set so as to offer the desired reliability. Failing to do this for a BE connection in the uplink direction, will mean under-utilization of the already limited bandwidth, which in turn affects the TCP's throughput. Moreover, TCP considers all losses as congestion-losses and hence, invokes congestion-recovery. So, the drops due to inappropriate settings of ARQ parameters will also be treated as congestion-drops, which cause unnecessary degradation in the performance of TCP. For uplink traffic, the drops occur in the first-hop, i.e. sender's ARQ drops the blocks. As concluded in Chapter 5, the optimal values for the ARQ parameters are dependent on the wireless network load and the channel quality. One solution to improve the TCP throughput is to adjust the ARQ parameters continuously, based on the RF channel quality and the network load. Another alternative to improve TCP's throughput is to notify the TCP about ARQ losses that are not due to congestion. This allows the TCP-sender to retransmit the lost segments without applying congestion-control and thereby increasing the throughput.

This work chooses the second alternative to improve the performance of uplink TCP. To implement such as cross-layer feedback approach, it is required to identify the ARQ drops that are not associated with
congestion. In a DAMA-based system such as IEEE 802.16, when ARQ is enabled for reliability, it is difficult to make out the reason for a MAC SDU drop as the blocks of the SDU would have been retransmitted many times due to error or lack of BR allotment, before getting dropped. The proposed scheme sends a feedback to TCP as soon as the ARQ drops an SDU. As this MAC feedback triggers a TCP retransmission without applying congestion-control procedures, the proposed system confines itself to check for congestion at the time of an SDU drop.

This chapter is organized as follows. Section 6.1 gives the overview of CDMA-based contention mechanism. Section 6.2 presents the analytical calculations of initial Start/End for the backoff-window and shows the effectiveness of the adaptive window through simulation. Section 6.3 depicts as to how the adaptive window adjustment could be used to identify the drops associated with congestion. In section 6.4, the proposed model is substantiated with the help of simulations carried out using NS-2. Section 6.5 concludes the chapter with a summary.

6.1 OVERVIEW OF CDMA BASED CONTENTION MECHANISM

In order to support non-real-time services, the IEEE 802.16-2009 standard defines two types of QoS, namely, non-real-time Polling Service and Best-Effort Service. These two services use contention-based BR mechanism to acquire an uplink allotment to send the data.

The WirelessMAN-OFDMA PHY supports two mandatory BR mechanisms. The SSs can either send the BR-header or use the CDMA-based contention mechanism. The OFDMA PHY specifies a Ranging-Subchannel and a subset of Ranging-Codes that could be used for CDMA-based BRs.
When requesting for bandwidth using CDMA-based contention mechanism, SSs select, with equal probability, a Ranging-Code from the code-subset allocated to BRs, modulate it onto the Ranging-Subchannel and subsequently transmit in a Ranging-Slot selected with equal probability from the available Ranging-Slots, on the UL subframe. This is termed as CDMA request. The SS can use either random selection or random backoff to select a Ranging-Slot. When random selection is used, the SS selects one Ranging-Slot from all the available slots in a single frame using a uniform random process. When random-backoff is used, the SS sets its internal backoff-window equal to the initial backoff-window \(2^S\), where \(S\) is the backoff-Start defined in the UCD message, and selects one Ranging-Slot from all the available slots in the corresponding backoff-window using a uniform random process.

Upon detection, the BS provides an uplink allocation for the SS, and sends it along with CDMA_Allocation_IE, which specifies the transmit region and the Ranging-Code that were used by the SS. This is used by an SS to determine whether it has been given an allocation by matching these parameters with the parameters it has used. The SS can use the allocation to transmit a BR or the data, and thus ends the contention resolution. If the BS does not issue the uplink allocation within the CBRTO, the SS assumes that the transmission of Ranging-Code resulted in a collision and follows the contention resolution procedure.

The contention resolution procedure is based on TBEB algorithm. The SS increases its internal backoff-window by a factor of two, as long as it is less than the maximum backoff-window, \(2^E\), where \(E\) is the backoff-End. The SS randomly selects a number within its new backoff-window and repeats the deferring process. If the transmission is not successful even after the internal window reaches \(2^E\), keeping the window fixed, SS can continue
the retry process until the maximum number (*request-retries*) of retries has been reached. At this time, the PDU is discarded. The maximum number of retries is also set by the BS and is independent of the initial and maximum backoff-window.

Figure 6.1 shows the flow involved in sending a CDMA request. The IEEE 802.16-2009 document specifies that the BS can either set Backoff-Start as 0 and Backoff-End as 10 in the UCD message or the BS may make the Backoff-Start and Backoff-End identical, and frequently update these values in the UCD message so that all SSs use the same backoff-window. The procedure for the selection of optimal backoff-parameters remains open.

Sayenko et al (2007 a) have derived the optimal values for backoff-Start / backoff-End and the number of Transmission Opportunities (TO) per frame for a BR-header-based bandwidth request mechanism. The number of TO is derived based on the worst case time that an SS can actually wait. This work proposes a method to derive the optimal values only for the backoff-Start / Backoff-End analytically for CDMA-based BR mechanism. The number of TO (Ranging-Slots for BR in OFDMA PHY) allocated by the BS is dependent on the total size of the allocation (including all service classes) as well as the size of an individual transmission and hence, omitted. Then a method is also proposed to identify the congestion by exploiting the optimal backoff-Start / backoff-End values derived.
Figure 6.1 Flow Control for Sending CDMA Request by SS
6.2 ADAPTIVE INITIAL/MAXIMUM BACKOFF-WINDOW-SIZE

6.2.1 Analytical Calculations of Start/End for the Backoff-Window

An SS, which is in need of bandwidth, selects one of the BR codes which are equally probable, and modulates it onto the Ranging-Subchannel, and subsequently transmits in a Ranging-Slot selected with equal probability. If $S$ is the backoff-Start power value, the Ranging-Slot is chosen from all the available slots in the corresponding backoff-window of size $[0 \ldots W-1]$, where, $W$ is $2^S$.

An SS can transmit a Ranging-Code successfully, if it generates a code or a slot that is not generated by any other SS. As per Sayenko et al (2007 a), the probability for a successful transmission in the first attempt by choosing a unique backoff-value (slot) is given in Equation (6.1).

\[
P_b = \sum_{j=1}^{W} \left( \frac{1}{W} \prod_{i=1}^{N-1} \left(1 - \frac{1}{W}\right) \right) = \left( \frac{W-1}{W} \right)^{N-1} \tag{6.1}
\]

where, $W$ is the size of the current backoff-window, whose value is between 0 and $2^S-1$, and $N$ is the number of active BE connections.

Extending the results of Sayenko et al (2007 a), the probability for a successful transmission by choosing a unique code is given by Equation (6.2).

\[
P_e = \sum_{i=1}^{C} \left( \frac{1}{C} \prod_{j=1}^{N-1} \left(1 - \frac{1}{C}\right) \right) = \left( \frac{C-1}{C} \right)^{N-1} \tag{6.2}
\]
where, $C$ is the number of codes allocated to BR, and $N$ is the number of active BE connections.

Therefore, the probability $p$ of a successful transmission in the first attempt is as given by Equation (6.3).

$$p = p_b + p_c - p_b * p_c$$  \hspace{1cm} (6.3)

where,

$p_c$ is the probability for a successful transmission by choosing a code that is unique.

$p_b$ is the probability for a successful transmission by choosing a backoff-slot that is unique,

$p_b * p_c$ is the probability for a successful transmission by choosing a value that is unique for both.

From Equation (6.3), the $p_b$ is

$$p_b = \frac{p - p_c}{1 - p_c}$$  \hspace{1cm} (6.4)

The value of $W$ can be found by substituting the value of $p_b$ from Equation (6.4) in Equation (6.1)

$$W = \frac{1}{1 - N \sqrt{\frac{p - p_c}{1 - p_c}}}$$  \hspace{1cm} (6.5)
The backoff-Start value announced in the UCD message represents a value that is power-of-two. The largest possible value is 15.

Hence, the value of $S$ is

$$S = \min \{ \lfloor \log_2 W \rfloor, 15 \}$$

(6.6)

By combining Equation (6.5) and Equation (6.6), the value of $S$ is given by Equation (6.7).

$$S = \min \left\{ -\log_2 \left( 1 - 2 \left( \frac{\log_2 \left( \frac{p - p_c}{1-p_c} \right)}{N-1} \right) \right), 15 \right\}$$

(6.7)

The next parameter of the contention resolution mechanism is the backoff-End. The SS applies TBEB algorithm (increasing the backoff-window by a factor of 2) for a maximum of $E-S+1$ retries. The probability of success in each retry is assumed to be the same. Applying geometric distribution, the probability $P$ of observing $E-S$ or fewer number collisions before getting a success is given by Equation (6.8).

$$P = \sum_{i=1}^{E-S+1} p(1-p)^{(i-1)}$$

(6.8)

where, $p$ is the probability of successful transmission in the $1^{st}$ attempt, as given in Equation (6.3).
From Equation (6.8), the value of $E$ is

$$E = \min \left\{ \frac{\log_2(1-P)}{\log_2(1-p)} + S - 1, 15 \right\}$$

(6.9)

To show the variation in Start and End of the backoff-window, a network load (active connections, which are chosen at random), shown in Figure 6.2 was considered. The initial probability ($p$) and the worst case probability ($P$) were set as 0.3 and 0.7, respectively. The number of codes allotted for BR was set as 16 and the value of $P_c$ was computed from Equation (6.2). The backoff-Start and backoff-End values were calculated by applying Equation (6.7) and Equation (6.9) and are shown in Figure 6.3.

![Number of Active Connections Chosen at Random](image)
Whenever the number of uplink active connections got increased, corresponding increases in the backoff-Start and backoff-End values were observed, which are essential to boost the probability of a successful transmission to the set \((p \text{ and } P)\) values.

![Graph showing Backoff-Start and Backoff-End values over time.](image)

**Figure 6.3 Dynamically Evaluated Backoff-Start and Backoff-End**

### 6.2.2 Simulation Model and Results

To analyze the Start and the End window parameters, comparison of simulation results, when BS relies on the static configurations, and when the BS updates the backoff-parameters adaptively, was performed. The amount of data transferred by all stations is considered in either case. NS-2 WiMAX Simulator Release 2.6 provided by the WiMAX forum was used to construct a WiMAX network with one cell and 30 SSs. Each station
established a BE connection on either direction with the BS during the first 20 ms. The parameters used in the simulation are reported in Table 6.1 and the simulation scenario is shown in Figure 6.4.

The simulation was carried out with Pareto application as the agent, and UDP as the Transport Layer protocol. The Pareto application running in each node, which can generate On/Off traffic with burst times and idle times, uploads data in the uplink direction to a wired-node.

**Table 6.1 Simulation Parameters-To Evaluate Dynamic Backoff-window**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame duration</td>
<td>5 ms</td>
</tr>
<tr>
<td>ARQ</td>
<td>OFF</td>
</tr>
<tr>
<td>PHY</td>
<td>OFDMA</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>10 MHz</td>
</tr>
<tr>
<td>FFT size</td>
<td>1024 points</td>
</tr>
<tr>
<td>Cyclic Prefix length</td>
<td>1/4</td>
</tr>
<tr>
<td>Modulation and coding</td>
<td>QPSK (\frac{3}{4})</td>
</tr>
<tr>
<td>bw_req_contention_size_ request retries</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Backoff-End – Backoff-Start + 1</td>
</tr>
<tr>
<td>UCD Interval</td>
<td>500 ms</td>
</tr>
<tr>
<td>BR codes</td>
<td>0-15</td>
</tr>
<tr>
<td>Pareto:</td>
<td></td>
</tr>
<tr>
<td>Burst_time_</td>
<td>500 ms</td>
</tr>
<tr>
<td>Idle_time_</td>
<td>500 ms</td>
</tr>
<tr>
<td>Rate</td>
<td>100 k</td>
</tr>
<tr>
<td>Shape</td>
<td>1.5</td>
</tr>
<tr>
<td>Packet size</td>
<td>210 bytes</td>
</tr>
</tbody>
</table>
Figure 6.4 Simulation Scenario - To Evaluate Dynamic Backoff-window

In 802.16 networks (ARQ not enabled), a MAC PDU is dropped either due to error or when the number of bandwidth requests exceeds the maximum retries. As the proposed scheme considers the amount of data transferred by all stations as the metric to evaluate the performance of the dynamically chosen window, no errors were introduced and hence, the drops are only due to the limitation in the maximum window. Similarly, UDP was chosen for Transport Layer, as this protocol will not recover any lost segments. Hence, the amount of data transferred is the direct measure of the dynamically adjusted window.

To find the active number of BE connections, the proposed scheme recommends a flag, named active_, for each UL connection. BS has to set this flag as 1, whenever a PDU arrives in the connection. The flag is to be cleared at regular intervals on expiry of the timer, active timer. Whenever UCD message is scheduled, the BS has to count the number of connections with active_ as 1. This count gives the number of active connections, which is applied with other parameters (p and P, which are set by the provider), in Equation (6.7) and Equation (6.9) to compute Start and End of the dynamic window. Figure 6.5 shows the steps involved in identifying the number of active connections.
Figure 6.5  Steps Involved in Identifying the Number of Active Pareto Connections

Table 6.2 Four Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Start</th>
<th>End</th>
<th>Average Data Transferred (KB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>1</td>
<td>6</td>
<td>6370</td>
</tr>
<tr>
<td>Scenario II</td>
<td>1</td>
<td>15</td>
<td>6503</td>
</tr>
<tr>
<td>Scenario III</td>
<td>7</td>
<td>15</td>
<td>6708</td>
</tr>
<tr>
<td>Dynamic</td>
<td>p = 0.4, P = 0.7</td>
<td></td>
<td>8033</td>
</tr>
</tbody>
</table>
Figure 6.6 shows the amount of data transferred by all SSs in the uplink direction. For each backoff-Start / backoff-End, the simulation was carried out 30 times and 95% confidence interval for the amount of data transferred was calculated. Four different scenarios were considered and are listed in Table 6.2.

![Graph showing the amount of data transferred](image)

**Figure 6.6 Amount of data transferred by all stations**

A small backoff-Start cannot ensure efficient connection due to large number of collisions (Scenario I). A larger backoff-End allows the SS to send more number of BRs (till the larger backoff-End is reached). Even though there may not be any loss, this process will consume more time and hence there was a slight increase in the amount of data transferred (Scenario II). If backoff-Start was set to a larger value (7), most of the Ranging-Slots will go idle and because of a larger delay, this setting cannot provide efficient connection (Scenario III).
The best results were achieved when the BS adaptively chooses the Start/End parameters. The simulation was carried out by setting $p$, the probability for a successful transmission in the first attempt as 0.4 and $P$, the worst case probability as 0.7. The BS has identified the number of active connections and has updated the Start/End values by applying the Equation (6.7) and Equation (6.9). The service provider has to set these values appropriately as they are dependent on other agreed QoS connections at that time.

### 6.3 IDENTIFICATION OF CONGESTION-LOSSES

The main drive behind this work is to send a feedback to TCP about the MAC ARQ drops that are not due to congestion. In this subsection, a scheme is proposed, which exploits the adaptively set window to identify if the network is congested. A network link is said to be congested when the offered load on the link reaches a value close to the capacity of the link (Forouzan 2002). In IEEE 802.16 networks, the BS schedules all UGS connections on a periodic basis by allotting data-grants of size negotiated at connection setup without explicit request from the respective SSs. For rtPS connections, BS allocates real-time, periodic, unicast request opportunities, which meet the flow's real-time needs and allow the SS to specify the size of the desired data-grant. BS schedules unicast polls on a regular basis to all nrtPS connections.

BS handles BE flows on a space-available basis with no minimum service level guarantee. SS sends requests for BW in either random access slots or dedicated TO. The occurrence of dedicated TO is subject to the network load. Hence, SS cannot rely on their presence. After allocating the BW required for all negotiated connections, the rest of the space is allotted to BE traffic. Hence, the data-grants allotted to BE connections is dependent on
the number of BW requests received and the bandwidth available, which will vary from frame to frame. From the perspective of a BE station (an SS having a BE connection), the network is congested, if the BR-grants is not allotted for its CDMA requests within the maximum retries.

SS in need of bandwidth (when blocks are ready) sends a CDMA request in a random slot within $2^N$. If the CDMA request is successful, BR-grant is allotted. SS can use this allotment to send the BR or data. Sometimes, the SS may not be assigned the BR allotment within the expected time. This can happen when the CDMA request is lost due to collision, or the BS is heavily loaded to allot one. In these cases, the SS uses TBEB method (by increasing the current window size by a factor of 2) to choose the next contention-slot. This process is repeated for request-retries times, after which the PDU is dropped. Deng et al (2012) have shown that the average network throughput increases with the increase in request-retries. Within the request-retries, for the first $E-S+1$ retries, TBEB is applied on internal backoff-window and for the remaining retries, backoff-window is kept constant. Let the number of retries made by an SS before getting be BR-grant be retry-count.

If the network is congested, the average number of retries made by an SS before sending a successful CDMA request will be larger than that of when the network is not congested. The proposed scheme uses this retry-count as the measure for congestion. Each SS computes the moving average of such retries made by it over a period on all successful allotments and on drops (the count is set as request-retries +1), and uses it to identify congestion.

If the backoff-Start value is statically set, and if it is smaller compared to the number of active stations, there will be unnecessary
collisions at the start, and the retries will be more. These collisions may be accidental. If the Backoff-Start is set larger, and if the SS chooses a larger number, the maximum number of retries may expire even before the SS gets a chance to send the CDMA request. In both the cases, it is hard to predict as to when the network is really congested.

Hence, the proposed scheme uses adaptive backoff-Start and backoff-End, derived in Section 6.2. By setting $p$ and $P$, the administrator indirectly restricts the maximum capacity of the BE traffic. To attain $p$, the backoff-Start is adjusted based on the number of active connections. The scheme considers E-S+1 retries and adjusts $E$ to realize $P$, the worst case probability. The reason for choosing E-S+1 retries in realizing $P$ is the inherent nature of TBEB, which applies exponential backoff for the first E-S+1 retries and spreads out the retransmissions and avoids congestion and thereafter contention resolution procedure doesn’t guarantee a successful transmission.

Once the Backoff-Start is set dynamically, there will not be any unnecessary collisions at the beginning. Similarly, dynamically adjusted Backoff-End will not go beyond what is essential to preserve the worst case probability. But the SS can continue trying even after reaching $E$, if request-retries allows. The transmission of CDMA request can be successful even after E-S+1 retries. In these cases, the average retry-count is likely to increase if quiet a number of CDMA requests take more than E-S+1 retries before a successful transmission or when a drop occurs. An average of retry-count less than E-S+1 indicates that the SS manages to get allotment by applying TBEB. While TBEB is taking measures to alleviate congestion and if the average retry-count is less than E-S+1, any drop during this period need not be considered due to congestion. An average of retry-count greater than E-S+1 means that the BS is able to allocate BW even after the SS has stopped
expanding the window. But, any drop during this time can be considered due to congestion as the backoff-window is fixed.

The proposed system allows the provider to choose the initial and final probabilities for a successful CDMA request transmission. To achieve the specified chances for a successful code transmission, the $S$ and $E$ are adjusted based on the number of active connections and announced in the UCD message.

![Diagram](image)

**Figure 6.7 Procedure for Identifying Active TCP Connections**

The BS computes the number of active TCP stations by applying the procedure shown in Figure 6.7. A variable, termed *active* is maintained for each uplink connection. Any uplink flow in a connection indicates that the SS is active. If there is a downlink flow, the associated uplink connection is
considered active, as the TCP-sender’s window is likely to open and data flow is expected in the uplink direction. Hence, the variable $active$ is set to 1, if either of these cases is true. When UCD message is scheduled, the BS counts the number of connections with $active$ equal to 1 and then resets $active$.

The IEEE 802.16-2009 standard recommends 10 s for the maximum UCD interval and has not mentioned the minimum UCD interval. The proposed scheme adjusts and announces $S$ and $E$ every 500 ms.

The moving average of the $retry-count$ is calculated using a form of exponential weighted average and is given in Equation (6.10).

$$aretry_n = (1 - e^{-\frac{-(t_n-t_{n-1})}{W}} \cdot retry_{cur} + e^{-\frac{-(t_n-t_{n-1})}{W}} \cdot aretry_{n-1}) \quad (6.10)$$

where,

$aretry_n$ is the new average of the $retry-count$

$aretry_{n-1}$ is the previous average of the $retry-count$

retry$_{cur}$ is the measured $retry-count$

$W$ is the duration in seconds over which the reading is said to be averaged

$t_n - t_{n-1}$ is the time interval between two readings in ms.

The duration over which the $retry-count$ is said to be averaged must be good enough to track the changes in the near past and smooth the
instantaneous changes. Figure 6.8 shows the moving average of `retry-count` for various durations for a randomly chosen `retry-count`.

![Graph](image)

**Figure 6.8 Instantaneous retry-count Vs Average retry-count**

This work obtains 500 ms-average of `retry-count`. As the values of S and E are updated every 500 ms, the same interval is chosen for calculating the average also.

Whenever an SS sends a BR request or drops a CDMA request, it updates the moving average and updates the flag named, `congestion flag`. The `congestion flag` is set to 1, if the average goes beyond E-S+1. When a block is dropped by ARQ, the `congestion flag` is tested to find if the block is dropped due to congestion. This information can be used to send ELN to the TCP-sender.
6.4 SIMULATIONS

Simulations were conducted to test if the moving average varies with instantaneous retries and the ARQ drops are due to congestion or not. An IEEE 802.16 network was constructed with 30 BE stations and 5 UGS stations. UGS connections were used by CBR applications to create background traffic. Each BE station has a TCP connection with a sink-node. The wireless loss model chosen uses a uniform distribution with a BLER of 0.1 to randomly drop blocks. ARQ is enabled for both the uplink and the downlink connections.

The initial and final probabilities for a successful CDMA request by an SS were fixed as 0.6 and 0.7, respectively. To realize these probabilities, initial and maximum backoff-window were dynamically adjusted by the BS based on the number of active stations and announced at every UCD interval. The UCD interval and the request-retries were set as 500 ms and 9, respectively.

Figure 6.9 shows the expected number of active SSs computed by the BS at the start of UCD interval and the actual number of SSs that were active during the previous UCD interval. As the BS cannot foretell as to when the SS is going to begin its transmission, the scheme cannot find the number of active connections during the start. The deviation in the actual and the expected number of connections is due to SSs carrying out TCP retransmissions as a result of RTO and ARQ retransmissions. These stations cannot be predicted by BS. This can be considered as a sudden increase in traffic. In these cases, the predicted S may not be enough to accommodate the SSs, and the stations will have to avail more CDMA requests to acquire bandwidth, which in turn increases the average retry-count. If the same scenario prevails, the average retry-count will go beyond E-S+1. Likewise, if
there is a sudden increase in traffic within the 500 ms UCD interval, S may not accommodate them and average *retry-count* will cross E-S+1.

![Graph showing expected and actual number of active connections over time](image)

**Figure 6.9** Expected Number of Active Connections and Actual Number of Active Connections

Figure 6.10 and Figure 6.11 show the instantaneous retry-counts made by two different SSs at each successful transmission of CDMA request against 500 ms-average of such retries. If the SS is not able to send its CDMA request within *request-retries*, the system assumes the retry-count as *request-retries* +1. On every successful transmission of a CDMA request or on a drop, the 500 ms average of the *retry-count* will be computed and maintained.
Figure 6.10  Instantaneous Number of Retries of a Connection Vs Average of retry-count (CID 16428)
Figure 6.11  Instantaneous Number of Retries of a Connection Vs Average of \textit{retry-count} (CID 16432)
Figure 6.12 shows the segments dropped by ARQ of the station considered in Figure 6.10. In this simulation scenario, E-S+1 is 2 (computed using $p$ and $P$). Hence, when the segments 16 (at 15.41 s) and 24 (at 16.51 s) were dropped, the average retry-count was greater than E-S+1 and these losses are not considered due to transmission error. When the segments 4 (at 11.16 s), 13 (at 15.21 s), 43 (at 21.56 s), and 56 (at 22.51 s) were dropped, the average retry-count was not above E-S+1 and hence, these drops are not associated with congestion.

Figure 6.12 Time instants: TCP segments dropped by ARQ and the 500 ms-moving average of retry-count of a Connection (CID 16428)
Similarly, Figure 6.13 shows the segments dropped by ARQ of the SS considered in Figure 6.11. The segments 32 (at 17.01 s), 72 (at 19.01 s), and 117 (at 25.21 s) were dropped when the network was not congested. The remaining drops 86 (at 19.76 s), 102 (at 20.96 s and at 21.36 s), 110 (at 21.81 s and at 22.56 s), 111 (at 22.56 s), 122 (at 25.66 s), 117 (at 25.66 s) were dropped when the network was congested. This can also be verified from Figure 6.14 which shows that the backoff-Start calculated by the proposed system and the actual backoff-Start that could have been appropriate for the actual number of connections. The offered backoff-Start during the identified congestion drops is lesser than the actual backoff-Start needed. This is because of the unexpected connections or more data from the predicted connections, which is actually an indication of congestion.

Figure 6.13 Time instants: TCP segments dropped by ARQ and the 500 ms-moving average of retry-count of a Connection (CID 16432)
6.5 CONCLUSION

In this work, backoff-Start and backoff-End for CDMA-based contention mechanism were derived based on the current number of active BE connections. The values were derived for the given p, the probability of a successful transmission in the first attempt, and P, the worst case probability. Simulations were conducted by setting these probabilities and the results showed that Adaptive Start/End outperforms the Static Setting in terms of the amount transferred.

![Graph showing Backoff-Start offered and needed over time.](image)

**Figure 6.14 Backoff-Start - Offered and Needed**

Then, the derived backoff-Start and backoff-End were used for identifying the wireless congestion. This indication can be used to decide whether an ELN is to be sent to the TCP-sender. When the network is marked as congested, any loss-event need not be informed to the TCP-sender.
The procedure for setting values for $p$ and $P$ is left open. These values are to be set based on the QoS parameters of other negotiated UGS, rtPS, and nrtPS connections.