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Re:	This document is in response to the 802.16.1 MAC Task Group CALL FOR CONTRIBUTIONS ON MAC-LAYER MODELING-Session #6 as contained in Published Document IEEE 802.16.1m-00/02. It is focused on the investigation of the robustness of the MAC protocol.	
Abstract	This document looks into the ability of the DOCSIS MAC protocol to recover from service disruption events such as unexpected shut down due to power failure. The issue is that unlike normal operation a large number of modems will attempt to range simultaneously as soon as service is restored. Modem populations up to 200 were used. The results presented in this study are applicable for Fixed Broadband Wireless systems using the DOCSIS MAC.	
Purpose	This document intends to give information about the time period that is required for a DOCSIS system (up to 200 modems) to recover along with the set of operational parameters, following an unexpected shut down due to metropolitan power outage. Having simulated conditions where such service disruption events have occurred (using both OPNET and C implemented models) we propose an extension to the MAC protocol where the knowledge of the network's status prior to disruption and the dynamic selection of various operational parameters can accelerate the recovery of the system. The case of battery backup is not considered, as it requires extra hardware at each subscriber station.	
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Fault Recovery of the DOCSIS protocol

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1. Introduction

The “Radio Transmission Systems for Fixed Broadband Wireless Access (BWA)” [2] is based on the approved and published by ITU-T cable modems standard (ITU-T J.112) but adapts the appropriate technical parameters for use in the wireless access environment. However, the Media Access Control (MAC) layer presents no differences from the Data Over Cable Service Interface Specification (DOCSIS) v1.0 [3].

An important issue for Fixed Broadband Wireless systems and Community Antenna Television (CATV) networks is the ability of the MAC layer to recover from service disruption events such as unexpected loss of power. These events could be due to a metropolitan power outage, replacing of transverters, sudden changes of transmission power caused by weather conditions or loss of link. Upon service disruption the communications between the BWA Base Transceiver Station (BTS) and the subscriber BWA modem are terminated. Once service is restored, all previous active modems attempt to re-register simultaneously via the Initial Maintenance MAP message, following an initialisation process (ranging). This time should be as short as possible in order to minimise service disruption.

In order to study the efficiency of the DOCSIS v1.0 MAC protocol under these conditions a discrete event simulation model has been created using the OPNET simulation package [5]. However, due to the low scalability of the OPNET model while using large Cable Modem (CM) populations, a simpler model was created based on [10] using the programming language C. These two models have been used to determine the system’s recovery time as defined by the number of ranging opportunities required for all CMs to register with the Head End (HE). The issue is that unlike normal operation a large number of CMs will attempt to range simultaneously as soon as service is restored. The main objective of this study is to identify the parameters affecting the recovery time period. The results presented in this study are applicable for Fixed Broadband Wireless systems using the DOCSIS MAC. The only consideration is the level of power variation which could be higher in wireless systems and also the power receive window of the BWA BTS could be larger. At the tests performed only the power outage case was considered. This means that the transmission power level the modem uses after the service is restored is within the range of the BWA BTS nominal receive power.

2. Problem Definition

After a service disruption event the CM must follow an initialization process in order to restore communication with the Cable Modem Termination System (CMTS, located at the HE). This procedure consists of the following steps (**Figure 1)**.

- Scan for downstream channel and acquire synchronization (SYNC Messages);
- Obtain transmit parameters (Upstream Channel Descriptor, UCD Messages);
- Perform ranging;
- Establish IP connectivity;
- Establish Time of Day;
- Transfer operational parameters;
- Registration and Service IDentifier (SID) assignment;
- Baseline Privacy (BP) Initialization.

Some work that has been done in this area is [6] where the performance of three Contention Resolution Algorithms (CRA) is studied in the case of station registration on power-up but without the restrictions of the DOCSIS protocol (the transmission protocol used was Slotted Aloha).

The elements that affect the recovery time are: the CRA used [1][6]; the transmission opportunities allocated by the CMTS for the ranging of the active stations; and the number of attempts the CMs may try before re-configuring their power parameters. The CRA that the DOCSIS specifies is the truncated binary exponential back-off algorithm. This study is aiming at the evaluation of the recovery ability of DOCSIS caused by a service disruption event and identifies the effects on the system performance when the operational parameters, such as *backoff start*, *backoff end*, number of ranging attempts per power setting etc., vary. The truncated binary exponential back-off algorithm determines the number of transmission opportunities that a station must defer before scheduling its own transmission. It is characterized by the backoff start and backoff end, integers between [0..15] as defined in DOCSIS, which are specified as part of the MAP message and represent a power-of-two value. The number of opportunities for each CM is calculated as a uniform random variable in the range of $[0..2^k]$, k = *backoff-window*, which initially is equal to the backoff start. In case more than one station attempts to transmit in the same transmission opportunity a collision occurs and no stations will be recognized by the CMTS. Both models assume that the CMTS can not differentiate between a collision and a non-transmission. The back-off window is increased by a factor of two, as long as it is less than the backoff end.

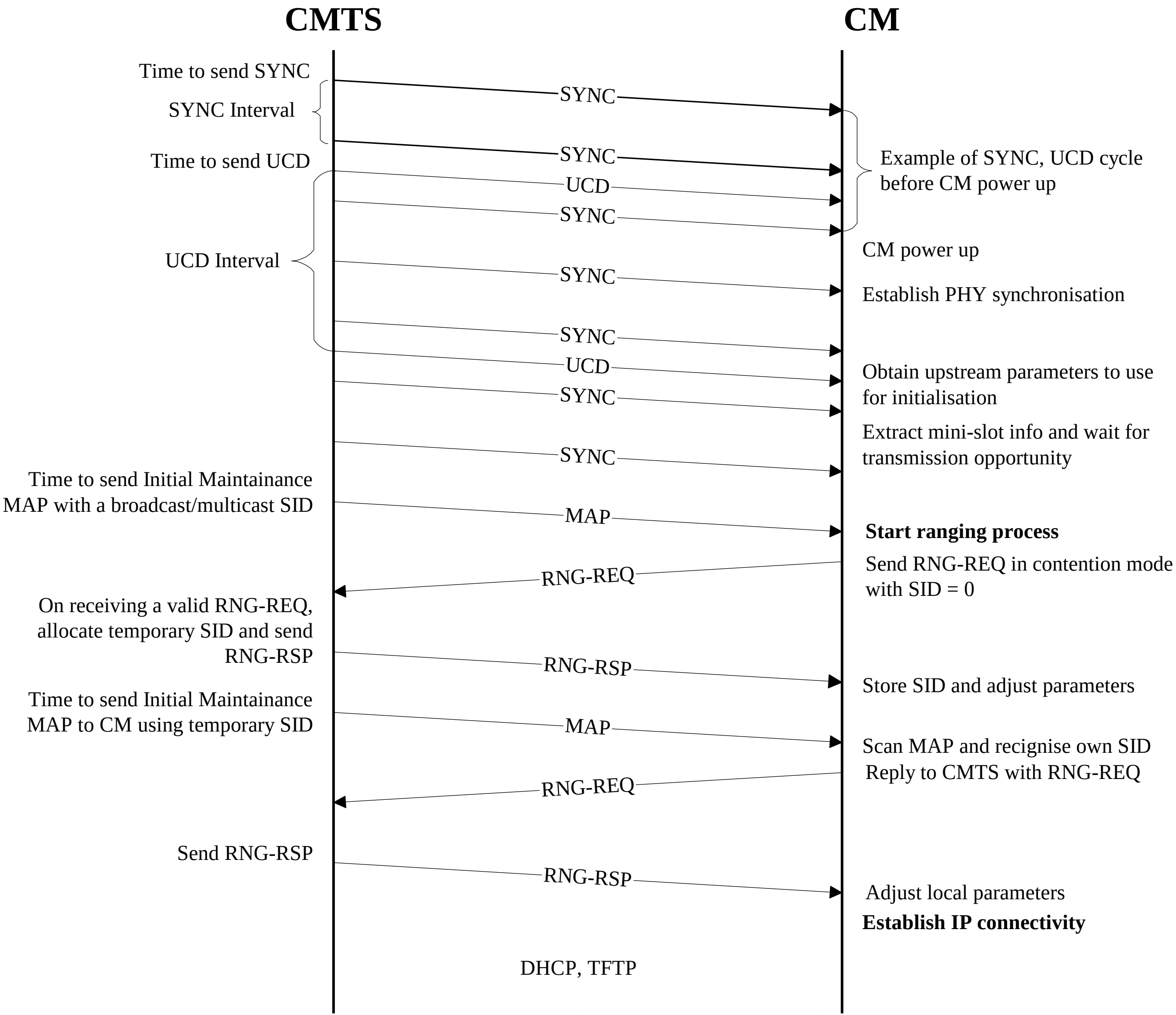

Figure 1. Initialization Timing Graph.

Once the back-off window reaches a value equal to the backoff end it remains constant. This re-try process continues until the maximum defined number of attempts (the maximum value specified in DOCSIS is 16) has been reached. Then the CM adjusts its power and reinitializes the process.

The ranging algorithm in DOCSIS, is required to adjust the transmission power every time a CM fails to range with the CMTS. However, in our study we used a partly different approach **(Figure 2)** Specifically, the CM tries to transmit using the same transmission power for a number of times equal to the predefined number of attempts. Only after this limit is reached the power parameters are altered and the process starts again. This variation was applied due to the fact that after a service disruption event a great number of collisions will occur since all CMs will try to range simultaneously. Consequently, the continuous change of power could result in CMs transmitting using power levels which are not within the power receive window of the CMTS. This would lead to an extra delay in the recovery of the system assuming that the correct transmit levels have not changed since the service disruption.

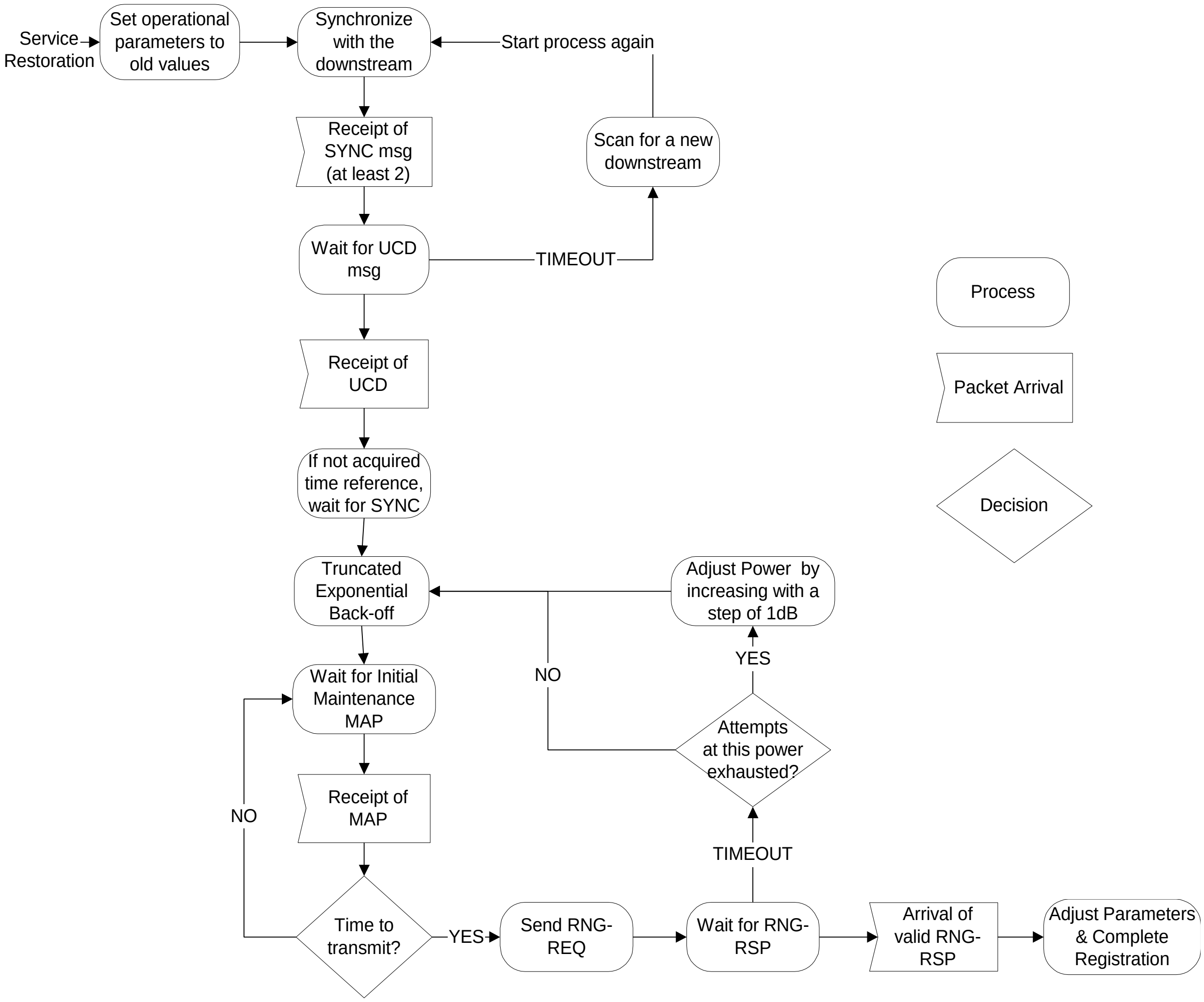

Figure 2. State diagram of CM initialization process after service restoration.

3. Simulation Models

For the purposes of this study an OPNET network model (RANGMOD) was developed based on the Common Simulation Framework v.13 (CSF13) model [5]. In RANGMOD model the ranging component was added **(Figure 2)** whereas every other function was removed in order to minimize simulation efficiency. The model consists of a single upstream and single downstream channel. The initialization procedure of a CM after service restoration is split into the following phases.

1. Set operational parameters to values established before the service disruption event. Considering that the CMTS receives at a specific power window of *nominal_power* ± *tolerance* and the previously active CMs are initialized using the old power level setting, then if the CM while re-configuring its power exceeds the CMTS power window it will fail to communicate with it due to incorrect transmit power setting (missed ranging power incident). In this study the value of *tolerance* used, is equal to 2;
2. Synchronize with the downstream channel (via SYNC messages);
3. Obtain transmit parameters for the upstream channel (from the UCD message);
4. Acquire time reference (via SYNC) unless it has already been achieved before the UCD was received;
5. Perform initial ranging, during which the CM attempts to transmit to the CMTS and waits for a response;
6. Adjust Time and Power parameters and complete registration.

A CM can establish communications with the CMTS if it has completed the ranging part of the initialization. Hence, in our model the system is assumed to have recovered when all the active stations have completed the ranging process. Afterwards the CMs can finish the registration by acquiring other operational parameters such as IP address, time-of-day, public key etc. from the operation support servers and be ready to transmit user data.

Although the OPNET RANGMOD model provides a complete and accurate representation of the CM initialization procedure its scalability and simulation time becomes an issue when considering large CM populations (>200). Specifically, the time needed to perform a series of simulation increases exponentially as the population of the active CMs in the network increases. Therefore, in order to be able to test the behavior of the protocol for cases where the number of CMs reaches or even exceeds 1,000 CMs a C model, RangeHFC, was built based on [10]. This model includes only the ranging part of the initialization procedure but it is much faster than RANGMOD which is based on OPNET. This allows not only simulating larger CM population scenarios but also to run the same scenario a number of times with different seeds for the random number generator and therefore obtain more accurate results. Having results from two models also allows validation of the results obtained.

4. Simulation Parameters

The parameters that were used in the tests performed both with OPNET (RANGMOD) and the C (RangeHFC) model are depicted in the **Table 1**. Note that in every Initial Maintenance MAP message one ranging opportunity is granted. Consequently, the CMTS serves 2 ranging opportunities/second.

Table 1. Simulation Parameters.

Parameters	Value
Number of CMs	25 to 200 by 25
Number of Attempts	5 & 16
UCD Interval	1s
SYNC Interval	3ms
Initial Maintenance MAP Interval	500ms
Backoff Start	1 to 11
Backoff End	1 to 15
Recovery Time Limit	1 hour

The backoff start increases from 1 to 11 with a maximum Ranging Window (RW, *backoff end – backoff start*) of 4, since when the attempts are equal to 5 the CM will begin the process again after the fifth attempt. An upper limit of 3,600s (1 hour) for the recovery time was used. A recovery time longer than one hour was considered unacceptable for a single upstream channel. Furthermore, the tests performed with the RANGMOD were executed with one random generator due to the extended simulation time required. The equivalent tests performed with RangeHFC were repeated 50 times and the average values are plotted.

The case study scenario that was used in these simulations was the power outage one. Specifically, it is considered that the transmission power that the CM uses after the restoration of the service is within the power receive window of the CMTS (signal attenuation is accounted for). Consequently, the CM does not waste time in order to detect the correct transmission power. However a missed ranging power incident might occur.

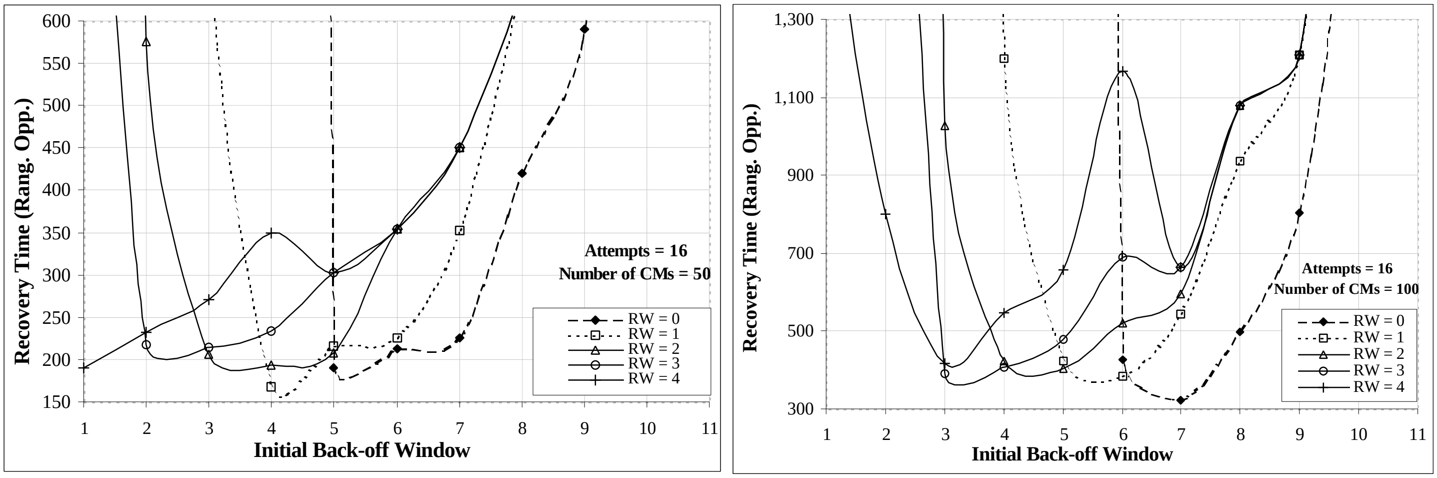

Figure 3. Recovery time for 50 and 100 modems (using RANGMOD).

5. Results & Discussion

The following figures depict the recovery time (measured in number of ranging opportunities accommodated by the CMTS) for different populations of CMs (50, 100, 150 and 200). Specifically, **Figures 3** and **4** present the results produced for 16 attempts from the RANGMOD whereas **Figures 5** and **6** depict the corresponding results from the RangeHFC. The results for the 5 attempts are presented in the Appendix (**Figures A1, A2, A3**, **A4**).

In each figure the curves corresponding to the different RW sizes (0-4) are parabolic in shape with a clearly identified minimum. The minimum of all curves is the best ranging time achievable by the DOCSIS protocol and the curve point where this minimum is realized specifies the optimum parameters, such as *backoff start/end*, for the specific CM population. As the backoff start increases, the number of collisions decreases and so the

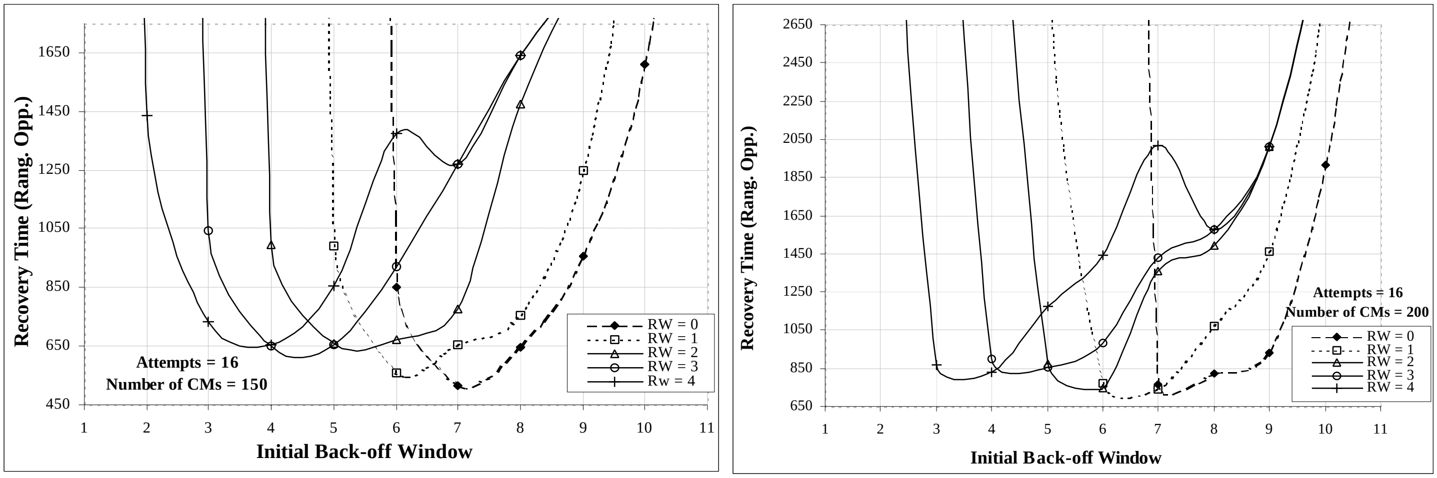

Figure 4. Recovery time for 150 and 200 modems (using RANGMOD).

recovery time decreases, until the value of the backoff start is sufficiently large to introduce a significant delay in its own right. Specifically, large backoff start values mean that the CM would defer for a large number of ranging opportunities, hence the prolonged ranging time. The deformity of the parabolic shape of the curves especially for RW sizes 2, 3 and 4 (**Figure 3** and **4**) is due to the fact that after a certain backoff start the collisions are resolved within the first four attempts. Consequently, a further increase in the backoff end has no effect on the recovery time. This deformity starts at backoff start of 3 for 25 CMs, 5 for 50 CMs, 6 for 75 CMs, 7 for 100-150 CMs, 8 for 175-200 CMs. At these convergence points the recovery time begins to be equal for different backoff end values.

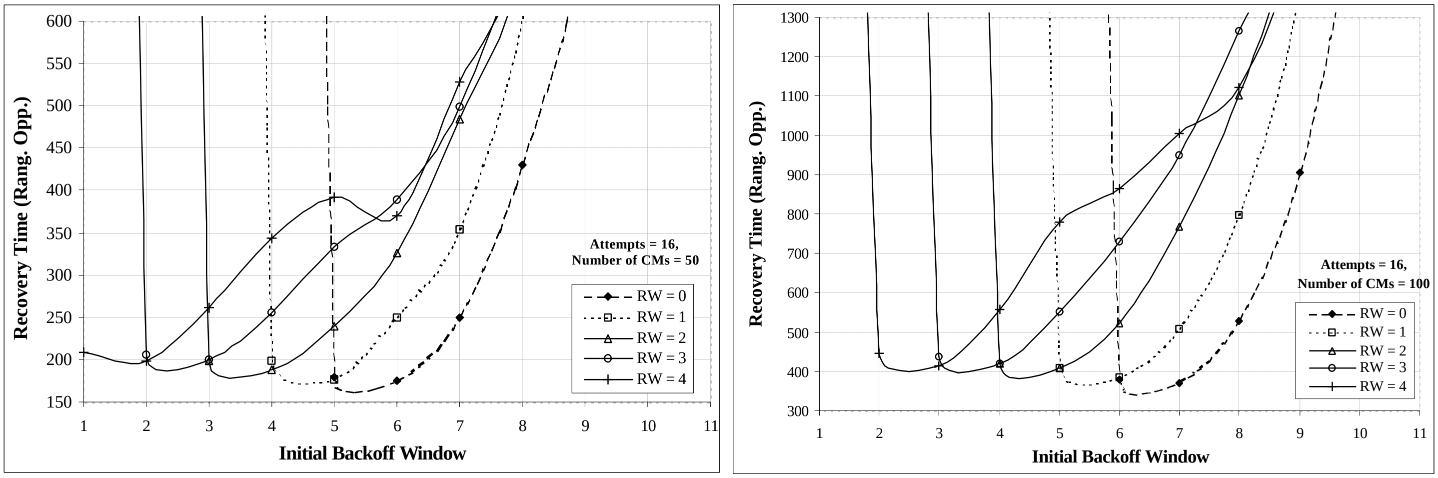

Figure 5. Recovery time for 50 and 100 modems (using RangeHFC).

The key feature across these plots is that the lowest recovery time for each number of active CMs occurs for different values of the backoff values. Consequently incorrect backoff values can result in a significant delay during recovery from a power outage. In few cases, as the number of CMs increases the system does not manage to recover within the maximum defined limit of 1 hour. This is due to the *missed ranging power incident* by which the CM falsely assumes that its power is incorrect after failing to complete the ranging process within the number of attempts allowed. As a result the CM re-configures its power parameters by increasing its power with a step of 1dB. If the CM exceeds the CMTS power receive window it will fail to range with the CMTS even if no collisions occur.

Figures 5 and **6** depict the test results generated by the RangeHFC model. Results reveal that the backoff start is more important than the backoff end in order to achieve minimum recovery time. Specifically, it can be noticed that the optimum recovery time is obtained for a backoff start value equal to 6, for 50 CMs, 7, for 100 and 150

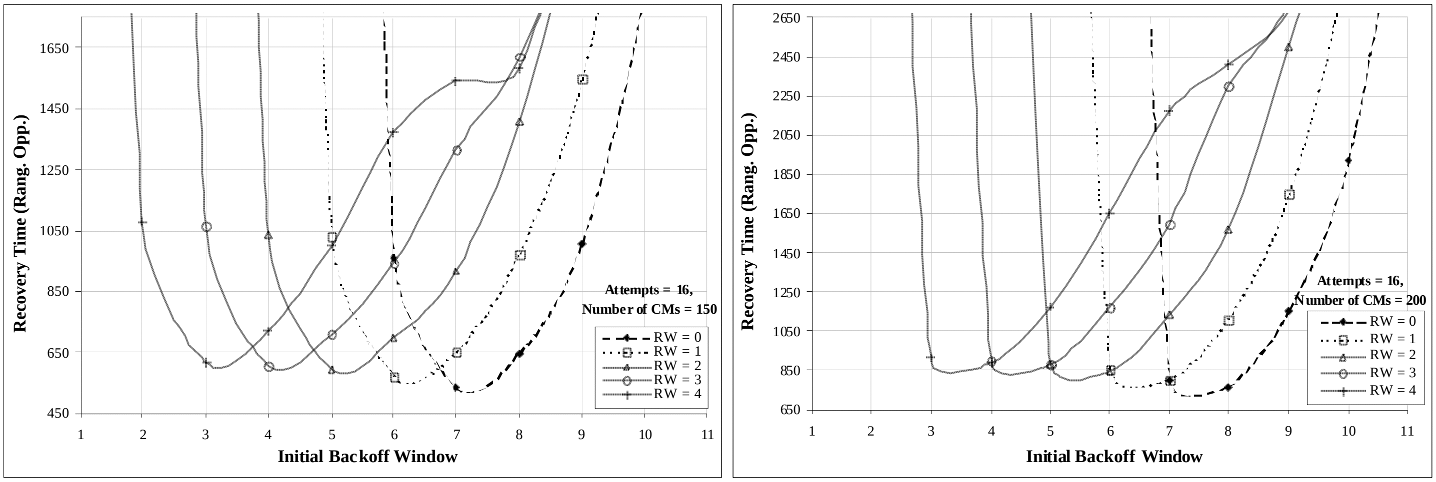

Figure 6. Recovery time for 150 and 200 modems (using RangeHFC).

CMs and 8, for 200 CMs (**Figure 7** and **Table 2**). When the backoff start is large enough, there will be fewer collisions when power is restored, as the number of ranging opportunities to defer is larger. In order to be able to compare closely the two models, **Figure 7** depicts the optimum recovery times for population of CMs ranging from 25 to 200, as obtained from the RANGMOD and RangeHFC (for 16 attempts). In the case of the RangeHFC except from the average value of the optimum recovery time, the minimum and maximum values are also depicted. Specifically, the recovery times that were obtained by RANGMOD were between 83%-107% of these obtained from RangeHFC. **Tables 2** and **3** list the backoff values for the optimum recovery time (the values express the number of ranging opportunities issued by the CMTS) for 16 and 5 attempts respectively. It is noted that the minimum recovery time for 16 and 5 attempts differ by a small number of ranging opportunities. This is caused by the fact that the average number of attempts performed by the CMs for the specific backoff values does not exceed 3.

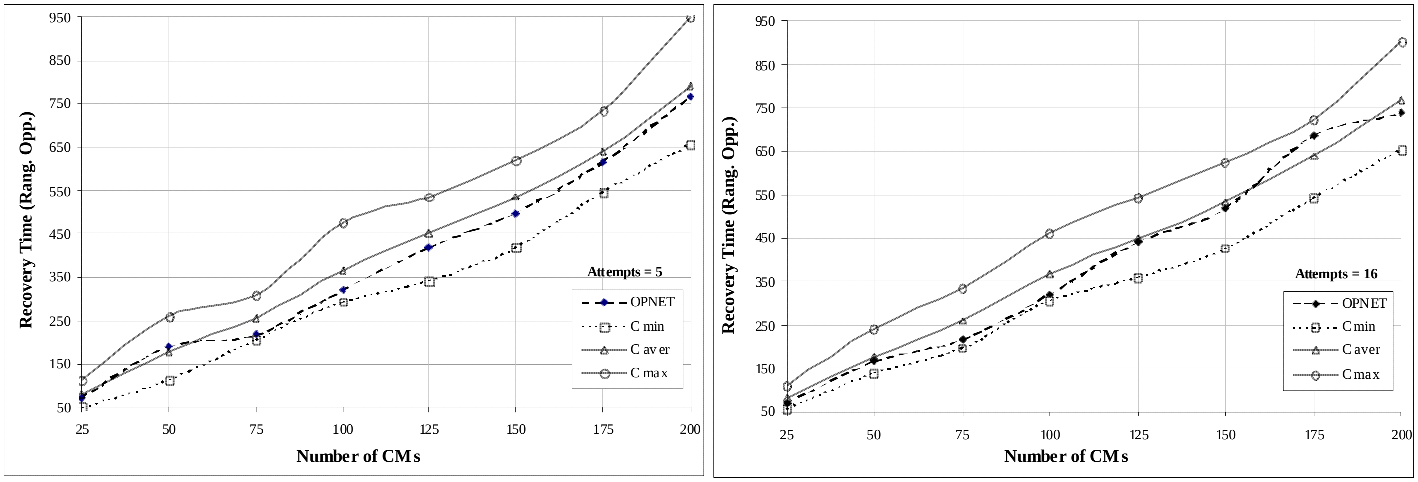

Figure 7. Optimum Recovery Times for 5 & 16 attempts (for both models).

Another interesting protocol characteristic is the distribution of the number of CMs ranged during the recovery period. Using the results for the optimum recovery time it is noticed that a sizeable percentage of the total time is wasted for the last 10%-20% of the CM population. **Figure 8** depicts the percentage of the optimum recovery time (measured in ranging opportunities) that a CM needs to range with respect to the time that the previous CM ranged for 16 and 5 attempts. Specifically, the last 15%-30% percent of the total recovery time is required by 10%-20% of CM population. This effect becomes more evident by plotting the number of CMs ranging rate for both 16 and 5 attempts per power setting (**Figure 9** and **Figure 10** respectively). The rate of ranging decreases rapidly for the last 10%-20% of the CM population especially in the 16 attempts per power level case.

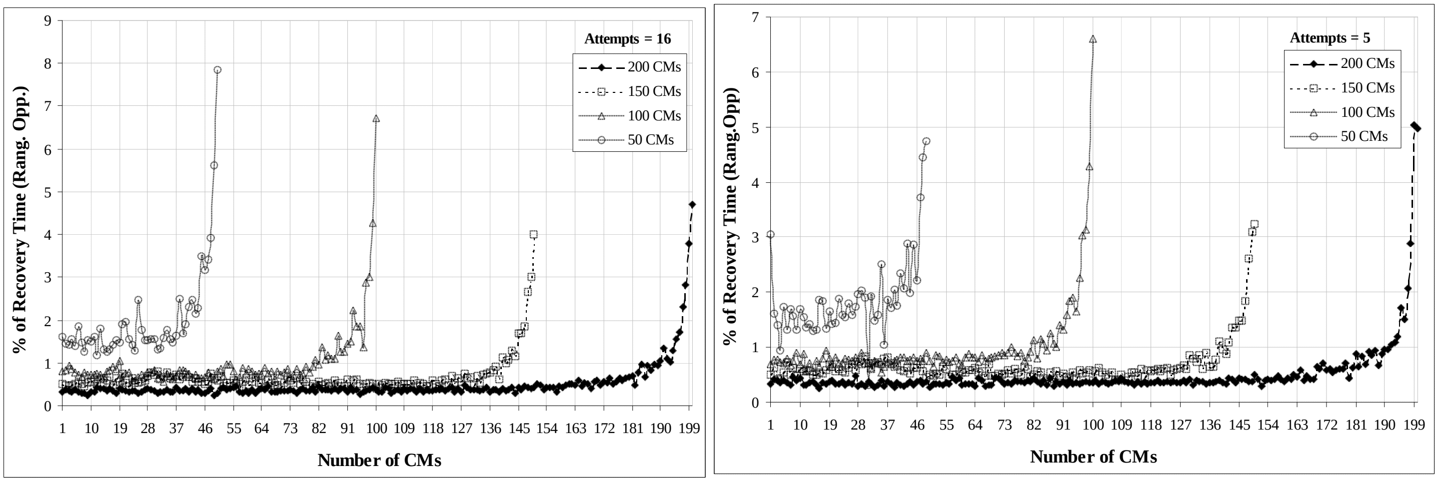

Figure 8. Percentage of Recovery Time per modem.

Table 2. Optimum Recovery Time for 16 attempts

	OPNET RANGMOD		C RangeHFC	
Modems	Recovery Time	Back-off start/end	Recovery Time	Back-off start/end
25	70	5,5	80.72	4,5
50	168	4,5	175.4	6,6
75	216	6,7	260.5	6,6
100	322	7,7	368.74	7,7
125	442	3,7	448.8	7,7
150	516	7,7	533.8	7,7
175	686	7,7	638.2	7,7
200	738	7,8	769.7	8,8

This is due to collisions the CMs experience along with the back-off algorithm used in DOCSIS. This is because the last CMs having large backoff values which results in many unused ranging opportunities. Hence the prolonged ranging time. This fact indicates that there can be an improvement in the ranging algorithm so as to achieve a lower recovery time.

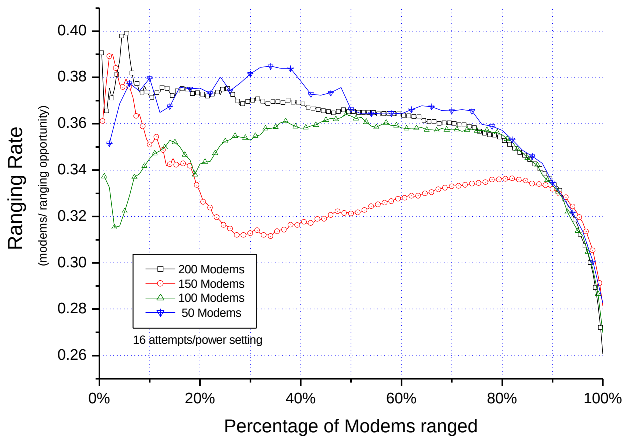

Figure 9. Ranging rate vs Number of CMs ranged (16 Attempts per power setting)

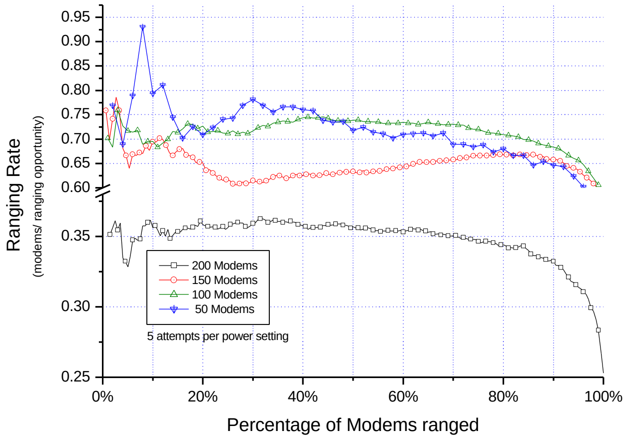

Figure 10. Ranging rate vs Number of CMs ranged (5 Attempts per power setting)

6. Conclusions & Future Work

This paper studies the recovery of a Data Over Cable Service Interface Specification (DOCSIS) after a service disruption event, such as a power failure. The outcome of a serious service disruption on a Community Antenna Television (CATV) network would be the simultaneous termination of the communications between the Head-End (HE) and the Cable Modems (CMs). Since the fast recovery of the system is necessary for service provision, identifying the parameters affecting this time and their optimal values is important for network management.

The results produced by the two models developed have shown that the backoff start of the Contention Resolution Algorithm (CRA) is the key parameter that affects the system recovery time. However, the optimum values of these parameters vary according to the number of active CMs on the network. Minimum recovery times of 534 ranging opportunities and 770 ranging opportunities for network architectures with 150 and 200 CMs respectively on a single upstream channel were obtained. The recovery time in seconds is obtained by dividing the figures presented with the number of ranging opportunities per second issued by the CMTS. This is operator-defined parameter.

An algorithm in the Cable Modem Termination System (CMTS, located at the HE), responsible for selecting the optimal values of the backoff start and backoff end as a function of the number of stations active on the network will accelerate the system recovery. These values would be passed to the CMs via the Initial Maintenance MAC management message.

Table 3. Optimum Recovery Time for 5 attempts.

	OPNET RANGMOD		C RangeHFC	
Modems	Recovery Time	Back-off start/end	Recovery Time	Back-off start/end
25	70	5,5	80.4	5,5
50	190	5,5	178.4	6,6
75	216	6,7	256.74	6,6
100	322	7,7	365.42	7,7
125	418	6,7	452.68	7,7
150	498	6,7	536.9	7,7
175	616	6,8	639.68	7,7
200	766	7,7	791	8,8

Summarizing, this study has proved that the DOCSIS MAC protocol is capable of providing a timely system recovery after a service disruption event, such as an unexpected loss of power, within a finite time period. The operational parameters can be optimized in order to provide optimum recovery times. Work in progress studies extensions and improvements of the registration algorithm that would decrease the recovery time and further improve the performance of DOCSIS, by extending the existing Media Access Control (MAC) protocol. Initial results of the priority scheme in the ranging process, where CMs contend according to their priority, have indicated a decrease in the recovery time of the system.

Acknowledgements

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References

[1] N. Golmie, Y. Saintillan, D. Su, “A Review of Contention Resolution Algorithms for IEEE 802.14. Networks”, *IEEE Communications Surveys*, pp. 2-11, First Quarter 1999.

[2] ITU, “Radio Transmission Systems for Fixed Broadband Wireless Access (BWA) Based on Cable Modem Standards (ANNEX B of ITU-T REC J.112)”, Doc. 8A-9D/TEMP/36, April 1999.

[3] MCNS Holdings, "Data-Over-Cable Service Interface Specifications, Radio Frequency Interface Specification", SP-RFI-I04-980724, July 1998.

[4] MCNS Holdings, "Data-Over-Cable Service Interface Specifications, Radio Frequency Interface Specification", SP-RFIv1.1-I01-990311, March 1999.

[5] S. Narayanaswamy, "MCNS Design Specification", *MIL 3 Inc.*, January 1997.

[6] D. Sala, D. Hartman, J. O. Limb, "Comparison of Algorithms for Station Registration on Power-up in an HFC Network*", Contribution to the IEEE802.14 WG*, No. IEEE802.14-96/012, January 1996.

[7] V. Sdralia, P. Tzerefos, C. Smythe and S. Cvetkovic, "Recovery of DOCSIS 1.0 CATV Networks after system wide service disruption", *2nd GEMISIS Technical Symposium on Multimedia-network-technology*, Salford, UK, May 1999.

[8] V. Sdralia, C. Smythe, P. Tzerefos and S. Cvetkovic, ”Performance Characterisation of the MCNS DOCSIS 1.0 CATV Protocol with Prioritised First Come First Served Scheduling”, *IEEE Transactions on Broadcasting*, Vol. 45, No. 2, pp.196- 205, June 1999.

[9] P. Tzerefos, V. Sdralia, C. Smythe and S. Cvetkovic, "Delivery of Low Bit Rate Isochronous Streams of the DOCSIS 1.0 Cable Television Protocol", *IEEE Transactions on Broadcasting*, Vol. 45, No. 2, June 1999.

[10] P. Tzerefos, “DOCSIS Performance Analysis and Optimisation”, Internal Report, September 1999.

Appendix. Results for 5 attempts.

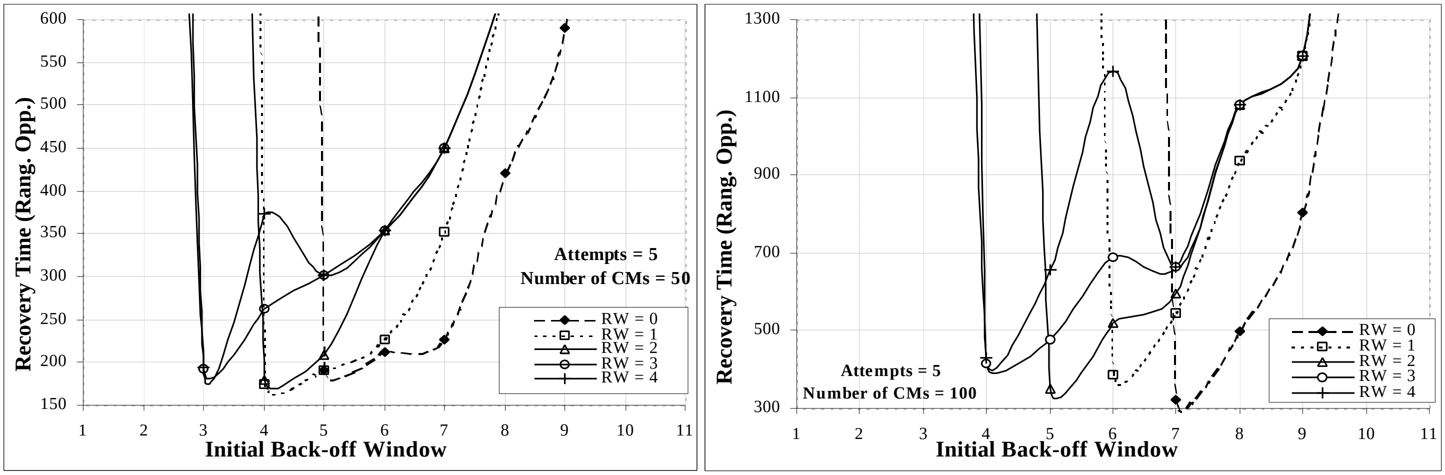

Figure A1. Recovery time for 50 and 100 modems (using RANGMOD).

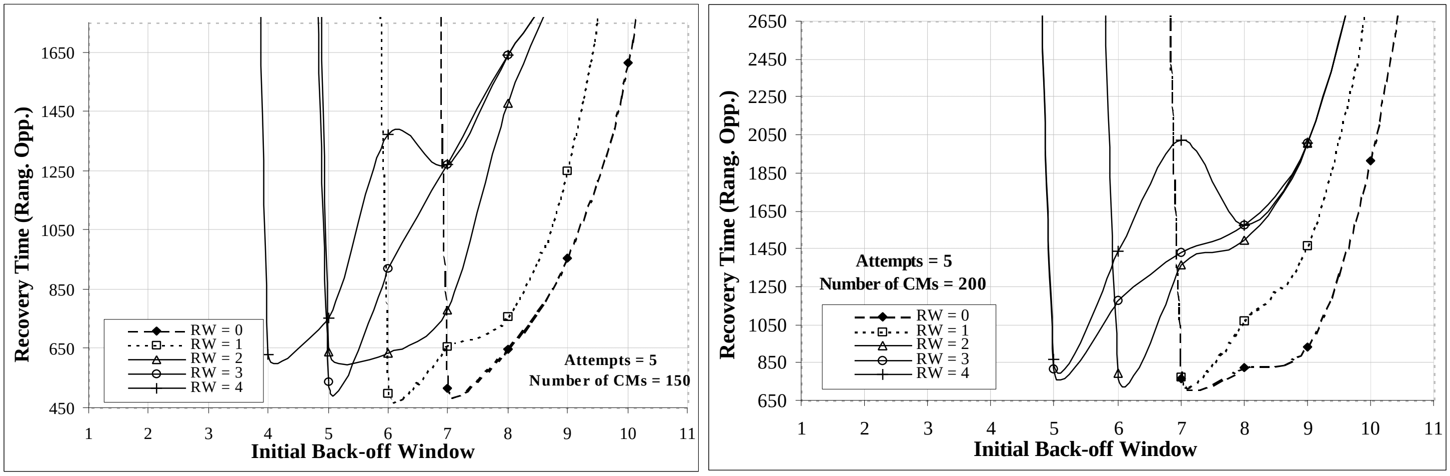

Figure A2. Recovery time for 150 and 200 modems (using RANGMOD).

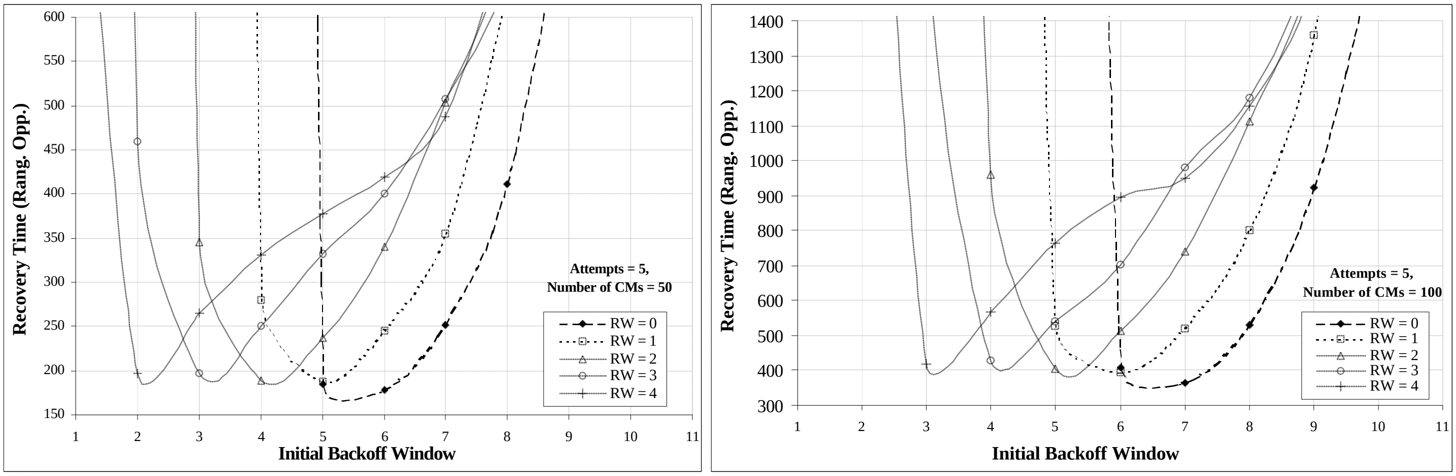

Figure A3. Recovery time for 50 and 100 modems (using RangeHFC).

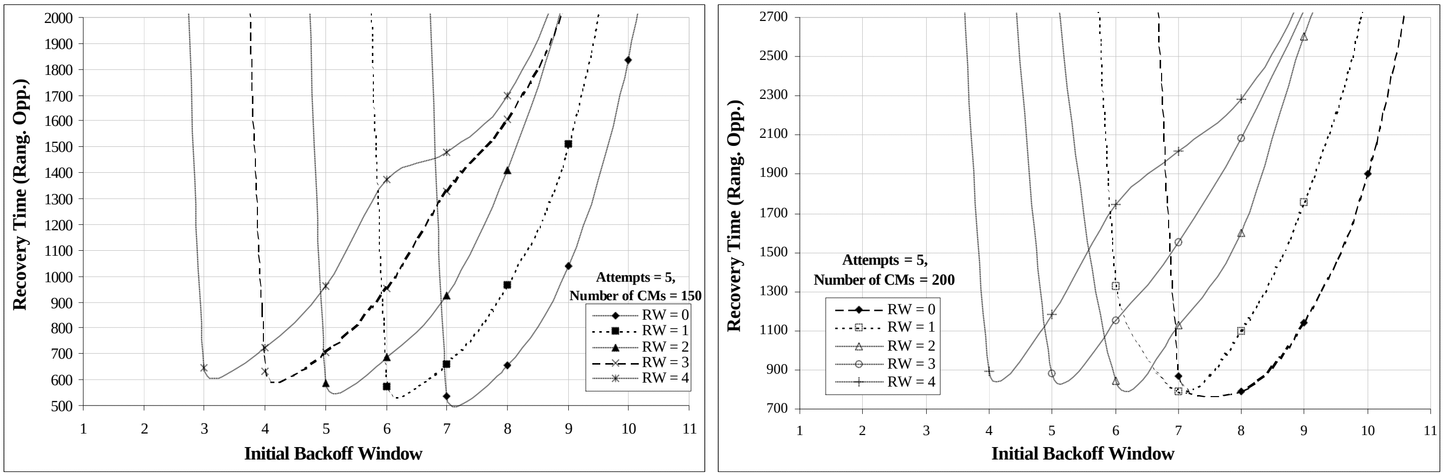

Figure A4. Recovery time for 150 and 200 CMs (using RangeHFC).