1 Introduction

The objective of the proposed research is to develop and evaluate a novel and high performance contention and reservation based medium access control (MAC) protocol for wired and wireless communications. The research work will start by improving on existing methods by defining a framework based on the medium access parameters (MAP) identified during the preliminary investigation. The research will continue with determining how to device a protocol to support this framework. This will result in the novel high performance MAC protocol which will then be evaluated and reported.

This research is unique in that it employs the MAP framework (MAPF) to exert more control over the contention access process and reduce its randomness. Randomness in contention access has always been a problem and will continue to be a threat for future generation systems. The research is also unique since it does not use contention resolution or splitting algorithms (CRA) to maintain network stability during operation; thus, avoiding service degradations. The protocol works within the MAPF by more precisely identifying contending users without going through a back off, tree, or p-persistence mechanism. The MAC protocol is thus guaranteed to be high performance due to the deterministic nature provided by the MAPF.

1.1 Origin and History of the Problem

The environment to be supported by this research is based on centralized systems. The protocol can be enhanced to support distributed and ad hoc environments, too. We start this proposal by providing general background information on centralized systems and MAC protocols.

1.1.1 The Medium Access Architecture

For a centralized system, users or subscriber equipments (SE) must go through a central controller or base station (BS) before gaining access to the network. The channel is divided into upstream and downstream where the upstream channel (UC) corresponds to the channel from SEs to the BS and the downstream channel (DC) runs from the BS to SEs. Figure 1 shows the system level architecture for end-to-end data services over contention and reservation based wired networks [1].

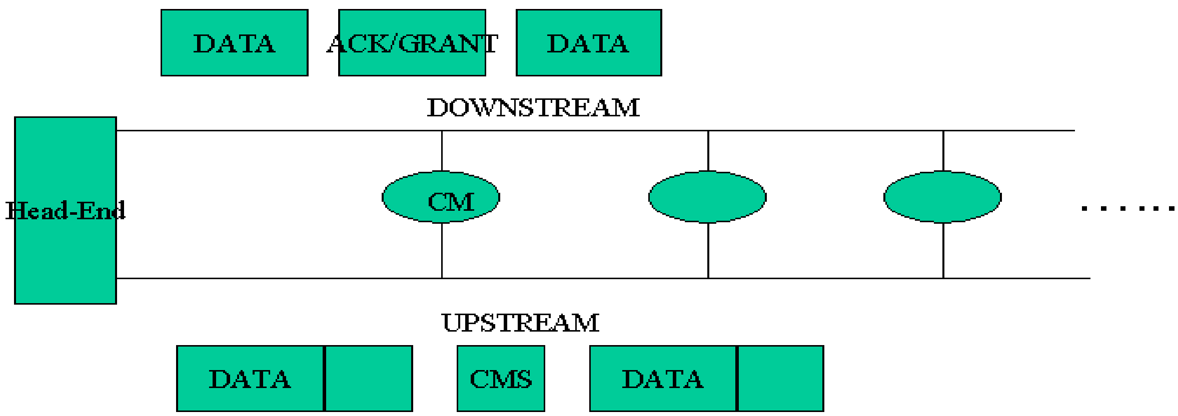

Figure 1. Abstract topology of a HFC cable plant.

1.1.1.1 The BS

The BS serves as the central location where signals from various SEs are received upstream and processed before being broadcasted to the subscribers downstream [2]. Off-air signals are collected using antennas. The servers located at the BS serves video and audio to the subscribers. The BS also serves as the gateway to the internet and public switched telephone network (PSTN). Most of the system complexity and expensive equipments are located at the

BS, but the overall cost gets amortized over the large subscriber base served over the shared medium. The developing protocol will be designed keeping this goal of central control in mind.

1.1.1.2 The SE

The SE is the terminal unit at the subscriber's end that helps a subscriber to transmit and receive data from the plant. In fact, a SE is a composite device that is part modem, part tuner, part encryption/decryption device, part simple network management protocol (SNMP) agent, and part Ethernet hub. The SE also must comply with the protocols running at the BS.

1.1.1.3 The UC

The UC typically takes 5% of the total spectrum. Since multiple SEs try to use this small spectrum at the same time, contentions occur at the UC. 16 QAM modulation is considered by this research for the UC giving a data rate of 2-3 Mbps [2].

For a typical contention based system, data slots (DS) are free from contention. A SE, with some data to send, requests some UC DS via contention mini-slots (CMS). Collisions occur when multiple SEs send their request to the same CMS at the same time. If a request from a SE is received by the BS successfully and processed, DS are allocated to the corresponding SE as governed by the grant mechanism [1-3].

1.1.1.4 The DC

No multiple access protocol is needed in the downstream direction since a single BS transmitter is used. If smart antenna arrays are used, only the transmission through the antenna elements needs to be scheduled.

Grants and acknowledgements to requests and the requested data are transmitted to the BS via this channel. There is no contention since only the BS can access this channel. Thus, this channel may be ignored for the proposed development.

1.1.2 MAC Protocols

Channel access protocols are used to provide the necessary coordination among the many potentially conflicting transmitters. How well protocols manage contention on the channel is usually measured in terms of the network's throughput-delay performance. Protocol performance depends primarily on how well the protocol is matched to networks' characteristics such as the traffic arrival process, topology, population size, channel propagation delay-to-transmission delay ratio, etc.

1.1.2.1 Conventional Multiple-Access

In general, protocols can be categorized by the amount of coordination they provide among network transmitters. Three major categories are possible: fixed access, demand access, and random access [4].

- Fixed Access: Fixed or scheduled access protocols such as frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access

(CDMA), and space division multiple access (SDMA) provide complete coordination among network transmitters. Channel contention is completely avoided by assigning each transmitter a particular sub-band, time slot, code, and spatial signature. A frequency sub-band or other resources is available to each transmitter whether it uses it or not.

- Demand Access: Demand access (reservation-based) protocols attempt to maximize network performance over the entire range of traffic loading by dynamically allocating channel capacity as a function of the current traffic load condition in an optimum manner [5]. Data contention is eliminated by allowing each transmitter to make a reservation for transmitting its packet in some future time slot. As slot reservations are made, the corresponding information packets form a network wide common queue from which they are transmitted without fear of collisions. These reservations can be made on contention basis as mentioned in Section 1.1.1 and this is the method that this research focuses on. The reservations can also be made by having the network system to query (poll) the transmission needs of individual stations [6]. Thus, the schemes used to provide for the access of stations onto the signaling channel, are divided into two categories: polling and reservation procedures [7]. Ideally, demand access protocols operate like ALOHA (with low delay) at low traffic loads and like TDMA (with high throughput) at high traffic loads. In ALOHA, stations transmit new messages on the channel as they are generated. ALOHA has low efficiency of channel use but this is offset by low access delay [8].

- Random Access: At the other extreme of network coordination, random access protocols provide little or no coordination at all. The simplest of the random access protocols, the ALOHA protocol, allows each terminal to transmit its packet as soon as it has one to send. All transmitters are allowed to contend freely for access to the network channel.

Should a collision occur, each terminal involved in the collision retransmits its packet after some random delay. Random access protocols provide short packet delay when the network is comprised of bursty transmitters and the average offered traffic load is low. As the offered traffic load increases, however, throughput decreases due to increased collisions and delay becomes large. Additional protocol coordination is necessary at this higher traffic load to maintain stability.

1.1.2.2 Contention Reservation Protocols

The centralized contention reservation protocols provide better timing mechanisms than the distributed ones in avoiding collisions. These kinds of protocols, proposed by many organizations, include MLAP (MAC level access protocol) of IBM Corp., XDQRAP (extended distributed queuing random access protocol) of Scientific Atlanta, Inc., ADAPt (adaptive digital access protocol) of AT&T Bell Laboratories, UniLINK protocol of LANcity Corp., FPP (framed pipeline polling) protocol of NEC Corp., CPR (centralized priority reservation) protocol of Georgia Institute of Technology, PCUP (pipelined cyclic upstream protocol), and FMAC [9-10].

Both PCUP and MLAP support integrated services and flexible contention and reservation modes of operation, where newly activated stations contend to establish themselves and then transmit on reserved time slots until they empty their queues. FPP works similarly, except the station transmits its data immediately after the BS polls it. In the CPR protocol, a station sends a request to the BS using a contention channel. The BS acknowledges the request in a first come first serve (FCFS) fashion, informing the station by means of a grant message about when to transmit. XDQRAP works similarly to CPR. It also provides an immediate transmission mode, allowing a single cell message to be transmitted without requests. ADAPt and UniLINK all support a mixture of isosynchronous, reservation, and contention bandwidth. The isosynchronous bandwidth is established by a setup process and exists before being released. The reservation bandwidth means that slots are on a per-request basis granted according to requests. The contention bandwidth is randomly accessed. Finally, FMAC uses finite projective planes where n SEs are divided into n sets. Since two distinct sets intersect at only one point, an arbitrary pair of active stations will compete exactly once in a frame of n slots. Thus, the FMAC scheme guarantees that the same group of stations will never collide successively. Successive collisions not only waste bandwidth, but also raise the concern of saturation in the channel.

The candidate protocols for contention reservation follows DAVIC (digital audio video council), DOCSIS (data over cable systems interface specifications), and IEEE 802.14 standards. All these standards employ a request/grant procedure for bandwidth allocation and uses random access for registration and random access. This characteristic is similar to the medium access structure provided in Section 1.1.1. For contention purposes, both the IEEE 802.14 draft standard and DOCSIS use mini-slots: a mini-slot is defined in IEEE 802.14 MAC as a slot size large enough to transmit 6 Bytes of information and overhead; whereas in DOCSIS, a mini-slot is defined as a power-of-two multiples of 6.25 μs. DAVIC uses a contention slot with a size of one ATM cell (53 bytes and 15 bytes of overhead). Besides using contention to request bandwidth initially, 802.14 and DOCSIS can use piggybacking for additional bandwidth request, while polling is an additional option in DAVIC. IEEE 802.14 does not impose a particular frame structure, whereas a 3-6 ms frame structure is recommended in DAVIC. This places 802.14 and DOCSIS in a favorable status to be chosen. DOCSIS can transport variable length packets (as well as ATM cells), whereas DAVIC and IEEE 802.14 rely on the granularity of a slot carrying a full ATM cell. This places DOCSIS on top of all the recommendations [11-12].

1.1.2.3 CRA

Although, the proposal eliminates the need for a CRA, it performs the role of a CRA implicitly by implementing the MAPF. IEEE 802.14 specifies a ternary tree CRA and both DAVIC and 802.14 recommends a ternary feedback mechanism (i.e., collision, no-collision, and idle), while the DOCSIS protocol employs backoff with binary feedback. Thus, DOCSIS protocols provide more flexibility in feedback [11]. However, DAVIC does not specify the use of a particular CRA which is an attractive feature for our cause. A few CRA algorithms are discussed next in order to provide an understanding of the role of the protocol later.

The major CRAs are the tree-based and the p-persistence CRA [13]. Maximization techniques to achieve optimal p-values were also developed [14]. A collision resolution and dynamic allocation (CRDA) protocol, which functions as an alternative to the CRA but uses backoff, was also proposed previously [15]. In Section 1.1.2.2, we talked about the FMAC protocol that could be used as a pioneer to CRA alternatives and intelligent and strong channel control mechanism.

In a tree algorithm, all users involved in a collision are divided in n sub-groups. Each user randomly selects the group to join. The first sub-group immediately retransmits in the first available CMS and the remaining sub-groups defer transmission until the transmission in all previous sub-groups has been resolved. A tree may operate in a blocked- or free-access manner. A blocked-access tree holds new arrivals until the current contention has been resolved. A free-access tree allows new arrivals to transmit immediately. The maximum stabled throughput with ternary splitting is 40.16%.

A p-persistent algorithm resolves contention by restricting the contending users to transmit in the next CMS with probability p. Thus, when a collision occurs only a portion of the users involved in the collision transmit in the next CMS and eventually the collision is resolved. There is no upper bound on the time required to solve the collision as oppose to the blocked-tree mechanism. The maximum achievable throughput is 36.7% [13].

The CRDA uses a collision and a bandwidth timer in SEs to check whether an acknowledgement (ACK) for a resource request (RR) has arrived from the BS on time. In case of delinquent ACKs, which may be due to collision or system overload, the SE resets the timers and reschedules another RR transmission attempt.

1.1.3 Analyses of the Problem

The problem of identifying a good candidate among the conventional medium accesses have been investigated and reported. Good comparisons were made to identify particular MAC protocols suitable for a given network architecture and traffic flow related constraints. The proposed research is unique and contributive because it analyzes and tries to solve the following problems devised during the survey:

- The research conducts an analytical survey on the pros and cons of conventional MAC protocol classes and suggests why a contention-based scheme outperforms the rest of the MAC methods for most practical systems. It also recognizes the circumstance that particularly favors contention mechanisms. This recognition of system parameters provides useful hints on the efficient MAC protocol design and MAPF constructions to aid the design.

- The research also compares polling and reservation methods for contention access and narrows down to one of these contention-based methods (reservation) only. This simplification does not only makes the problem of improving MAC much easier to solve but also permits further advancement to MAPF constructions.
- The research also surveys on current standards that support MAC protocols as discussed earlier. It chooses one of the standards (DOCSIS) that could be intertwined with the “state of the art” requirements of quality of service (QoS) with the incorporation of one feature from DAVIC recommendations.
- The research investigates CRDA and FMAC and continues its search for similar protocols that supports the MAPF construction partially to build the complete MAC protocol for MAPFs. This also helps identifying the basic parameters as they are used in these protocols designs.
- The research uses implicit collision performance metrics such as throughput-delay performance as well as explicit metrics such as contention itself. The delay or other parameters is analyzed on a per flow or aggregated basis. Analyzing these metrics leads to the formulation of the MAPF parameters. Also, traffic arrival process, topology, population size, channel propagation delay-to-transmission delay ratio, and other typical parameters are checked for prospective MAPF parameter candidates. Moreover, parameter candidates based on our past research are also investigated to complete the MAPF. These candidates are the active SE and traffic density/distribution and data-to-contention slot ratio (DS/CS) for a cluster or region. Furthermore, additional parameters for the wireless channel (due to mobility, interference, and environment) are considered for the wireless MAPF.

- The research finally develops and integrates a MAC protocol to MAPFs and simulates the scenario to compare with the existing methods and report on its performance improvement over them. The simulator characterizes the traffic at a single SE node as empty, waiting, or transmitting [16]. It also keeps track of the queue at each node and times the waiting period for all the requests that has been generated during the simulation period. It drops traffic off the queue for outdated requests and accounts for them as well. Figure 2 depicts this simulation architecture for individual flows. The next section provides more details about this topic, obtained during the preliminary investigation.

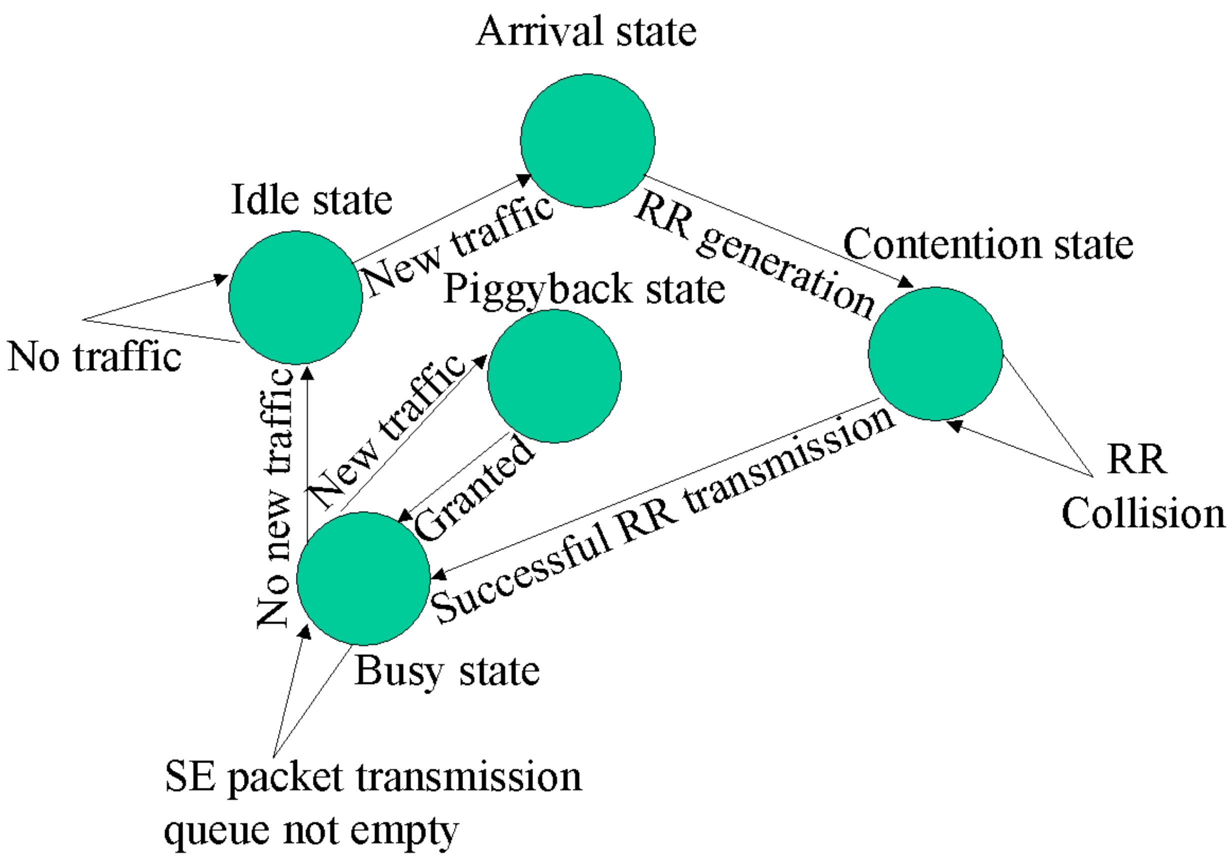

Figure 2. State diagram of a single node (SE).

The simulator realizes the centralized control by aggregating the independent SE flows and analyzing them with respect to the channel capacity and current network load condition. The buffers for variable services are also maintained during the operation by regularly filling, emptying, and monitoring them. A buffer gets filled when capacity requests for that particular service are granted for the next upstream (remember, we only consider the upstream case as discussed before). Similarly, the buffers start to be emptied when the amount of requests for bandwidth drops and the old requests are serviced properly. Section 1.2 elaborates this architecture further as the preliminary research has established some more facts on this phase of the simulator development. Figure 3 shows the process of BS implementation and channel management. Thus, the simulator can monitor each SE along with the whole channel. This allows for a complete collection of statistics on the channel and performance metrics. It is quite problematic to work with some simulators that do not allow these kinds of flexibilities as multiple layer operations embedded with the standard software package for those simulators makes it very time consuming, impossible, and inefficient to run such simulations. The study of the system architecture and the operation model, which is very important to construct the protocol from the MAPF and analyze it, is also easier when the system can be break into peaces as the proposed simulator does [17]. Furthermore, the simulator chooses among traffic sources for more realistic and definable behavior of the traffic flow and system operation. Section 1.2 provides more details on the necessary traffic pattern, which has been observed during the preliminary research phase, and the developed traffic model.

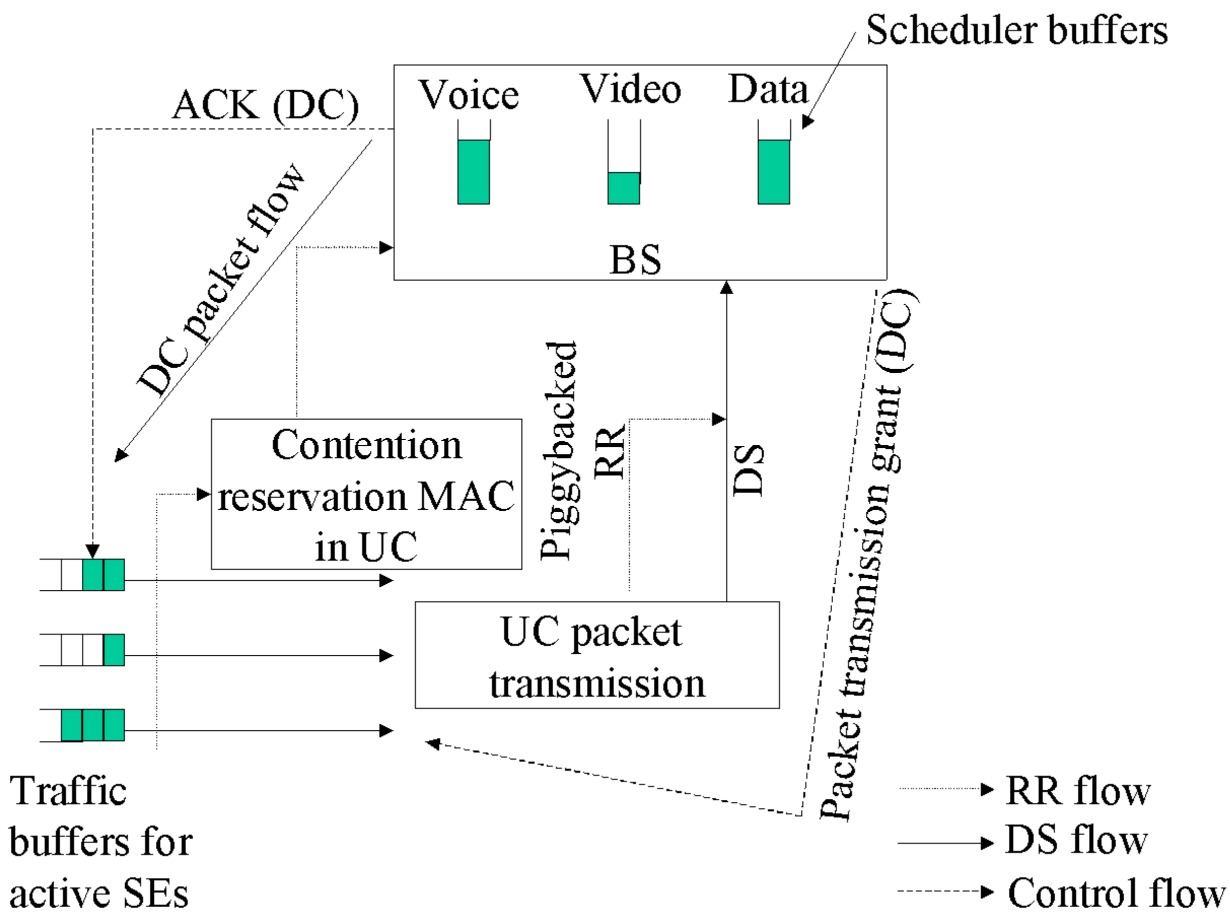

Figure 3. Packet transmit-permission policy.

1.2 The Preliminary Research

The preliminary research suggested why a contention-based scheme outperforms the rest of the MAC methods for most practical systems. It also recognized the circumstance that particularly favors contention mechanisms. The completed work also compared polling and reservation methods for contention access and narrowed down to one of these contention-based methods (reservation) only. The research also surveyed on current standards that support the MAC protocols as discussed earlier. It has chosen the DOCSIS standards with DAVIC's "no particular CRA” trait as it can be intertwined with the “state of the art” requirements of QoS. Furthermore, this preliminary investigation identified the parameters for both the wired and wireless (mobile and fixed host) MAPF construction and the broad MAPF structure to be exploited for the protocol design. Finally, we developed the basics of the simulator, experimented with it, and reported it to be operating satisfactorily. The simulator will be able to test the MAC protocol performance with minor modifications and reduced assumptions for more reliable results.

1.2.1 Comparison Among Medium Access Types

Fixed access MAC protocols waste bandwidth when a SE does not have anything to transmit. Most modern system’s users follow a random semi-Markov pattern, which means that there are indefinite periods when a SE will not transmit and the transmittable data burst size is variable [18]. Random access protocols are an improvement over fixed access schemes when the load is average and less collision lead to a uniform system utilization [19]. However, at very low or at very high loads, the random access scheme either underutilizes the bandwidth due to unpredictable collisions or becomes unstable and highly lossy, respectively. Both the fixed and random access schemes suffer due to their nature of keeping less knowledge of the network. The fixed access assumes everyone will have something to transmit and the random access is prone to the uncontrollable collision related high bandwidth loss. However, the contention mechanism is certainly an improvement and it has been proven to be more efficient than the other methods [20]. The contention mechanism provides more control over the network data through the contention, reservation, and scheduling steps. Although the contention step is random, it reduces the assumption of all users must occupy part of the spectrum. On the other hand, the reservation and the scheduling guarantees low loss of huge bandwidth space (data) as oppose to the random access scheme.

1.2.2 Comparison Between Polling and Reservation Contention

Polling based contention methods suffers from the same problem as the fixed access system's *all users will be transmitting* assumption. As a result, polling fares better than reservation at high loads but only if a smaller round trip time is assumed which makes the system too restricted to be considered under modern communications perspectives [21]. Test results have confirmed that the contention access mechanism always performs better than polling, if the capacity of the contention channel is correctly designed [22]. This can be done by assigning a proper fixed number of slots per frame to the contention channel or, better yet, by adopting an adaptive access scheme.

1.2.3 Choosing A MAC Standard

DOCSIS is chosen with an additional DAVIC specification/modification among the three existing standards discussed. This is because DOCSIS has the following advantages:

- DOCSIS uses the same request/grant type reservation procedure, the same random access for registration and bandwidth request, and the same fixed access for data transmission procedure as the two other leading standards (802.14 and DAVIC).
- DOCSIS uses a mini-slot size defined as a power-of-two multiple of 6.25 μs for contention access. This reduces the bandwidth loss as smaller losses are

encountered when collisions occur or a CMS is idle or unused. Simulation results demonstrated that the smaller-size CMS in DOCSIS protocols provides a significant performance improvement for traffic types with the small request size and high contention load (for example, WWW traffic and bursty traffic) [11]. However, for traffic types with a large request size and low contention load, DOCSIS still provide high performance due to the piggybacked request feature where new requests can be piggybacked to an upstream DS.

- DOCSIS uses variable length MAC messages (802.2 LLC frames) which means that it can transport variable length packets including ATM cells. This makes DOCSIS protocol the only current candidate MAC technique that directly supports variable-length packet data units (PDU); thus, providing a significant throughput advantage for traffic types that generate variable-length packets.
- Finally, DOCSIS uses a binary feedback which is accepted for this research and is a wise choice that many networks have adopted [23]. However, DAVIC's "no particular CRA" standard also needed to be incorporated (when colliding SEs at a later stage are considered) to reach the objective of this research.

1.2.4 The Construction of MAPFs and the MAC Protocol

A MAPF provides a framework that can be used to form clusters or groups of users to have a regional network for easier monitoring and control. This grouping is only possible when important medium access parameters are used to build MAPFs. The clustering process using MAPFs is the ultimate goal of this proposal. However, constructing MAPFs is the early step.

Fortunately, required MAPF formats are developed along with the other completed work mentioned in this section. The research used implicit collision performance metrics such as throughput-delay performance as well as explicit metrics such as contention itself. The delay was analyzed on a per flow or aggregated basis. The other parameters could also be analyzed as such. Analyzing these metrics leads to the formulation of the MAPF parameters. Also, traffic arrival process, topology, population size, channel propagation delay-to-transmission delay ratio, and other typical parameters were checked for prospective MAPF parameter candidates. These parameters were replaceable with the parameter candidates from our past research. These generic candidates are the active SE and traffic density/distribution and DS/CS for a cluster or region. Quicker means to form the clusters can be found and optimization parameters with their equilibrium (maximum efficiency) points can be investigated for the final protocol with complete MAPFs for wired and wireless networks.

In addition to these common parameters for all environments and particularly only parameters for the wired scenario, there are several wireless candidate parameters that we have accredited. The wireless parameters can be divided into fixed and mobile host parameters. The fixed host parameters are blockings by buildings or other objects and nearby-transmitter interference (propagation and channel loss and noise are ignored). The mobile host also has these two parameters. The difference is that the mobile host adopts the interactive form of these parameters which means that the SEs interfering/blocking ongoing transmissions on their track were accounted for in the wireless mobile MAPF.

The following discussion about these parameters is based on initial test results that were obtained using the simulator developed by us. These discussion and results confirm the user density/distribution and DS/CS for a cluster or region as the leading parameters for any MAPF.

The user density function includes the buffer capacity, differentiated service resource requirements, and new request arrivals. DS/CS acts as the basis parameter that is the basis of the analysis but improves little once somewhat optimized. Thus, the user density/distribution function plays the most significant role in performance improvement once DS/CS ratio is somewhat optimized and provides the highest clustering capability to guarantee QoS.

We ran our simulation on variable numbers of DS and CS over a 24 second period. Although the number of DS and CS were changed, their overall numbers were held constant due to the specifications that we have decided on earlier. We have shown the results of the simulations in Figure 4. The figure indicates that increasing the number of CS has the advantage of reducing collisions. However, this does not necessarily mean that the overall channel performance has improved. In fact, the channel performance degrades if fewer DS were used since although large quantity of CS reduces the collision, lower throughput results from the lower rate of data transportation. Figure 5 shows the throughput characteristics for the same cases as in Figure 4. Notice that, for the extreme case where number of DS is four times higher than that of the number of CS, there is no throughput and the collision rate is 100%. This test is designed to check the consistency for the rest of the graphs in our simulator. The solid line on Figure 5 is coincident upon the time axis showing no throughput where it shows 100% collision in Figure 4. This simply is the test case where 100% collision means no throughput. This happens when a much smaller number of collision slots are used compared to the number of active stations [24].

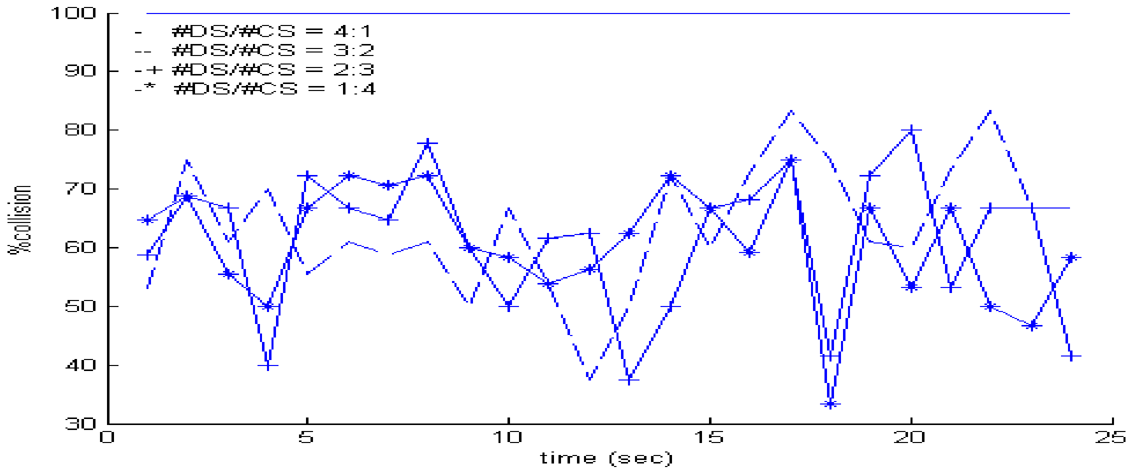

Figure 4. Collisions for different numbers of DS and CS for a UC.

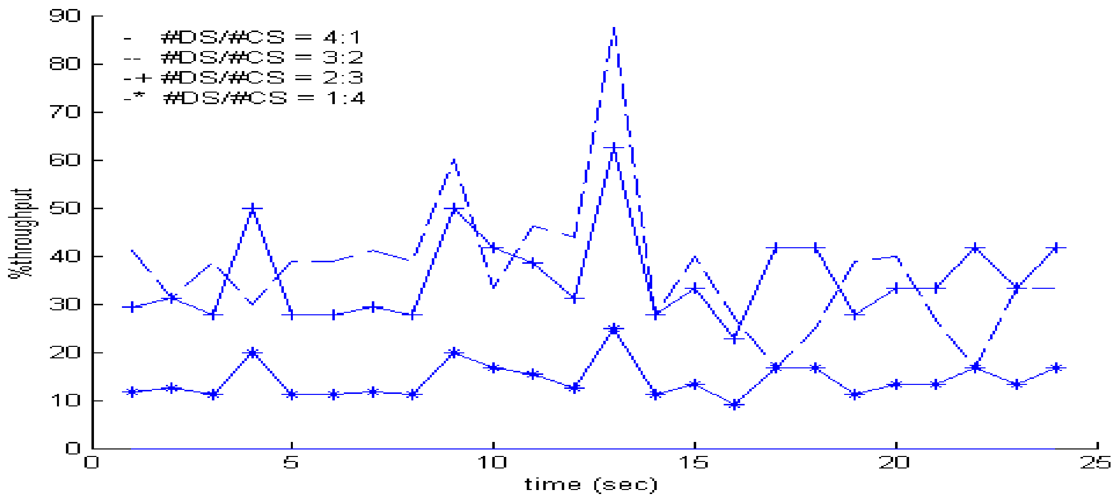

Figure 5. Throughput for different numbers of DS and CS for a UC.

To optimize the situation, one upstream channel seems to be an inadequate choice for collision reduction and throughput increase at the same time since the upper bound of performance is limited due to the restrictions of a single network. Hence, it would be a vantage to be able to dynamically divide up the network and optimize on each portion for a given load condition at a given time. This suggested us to modify the simulator further so that we can test the validity of user density function and its possibility to be used for clustering.

We modified our simulator and checked for the three cases where the network was divided into two equal divisions, one-third and two-thirds, and one-fourth and three-fourths. The numbers of DS and CS were kept constant. We have shown the results from one such simulation in Figure 6. Although the improvement is clear, as we have expected, in some cases, some divisions did not show any improvement for a certain load and channel condition. That's why there is no one choice of division and the algorithm needs to be dynamically adjusted for varying conditions and powerfully optimizing the result. We have also calculated the overall reduction in collision as an rms value for each of the divisions. On average, it tends to be 40% - 45% below the case where no division is applied. The credit also goes to the fact that the merit of divisions allows smaller number of stations to contend on a divided network. This definitely improves the performance when intelligently divided since in each portion of the network, a balanced number of stations contend and hence, collision is reduced. Thus, the division of the network provides more controllability for the BS. Also, the randomness associated with each of the network segments opens possibilities to have less collisions in at least a few regions where if only one channel is used, the whole channel may end up with high collision in a more random manner. With this kind of statistical and prediction dependent scheme, each region can provide for a certain rate of data transmission, collision, and mean delay/jitter. The regions would thus allow for better controllable QoS for a given region and may even be designed to take QoS into consideration for a given region by dividing the regions accordingly.

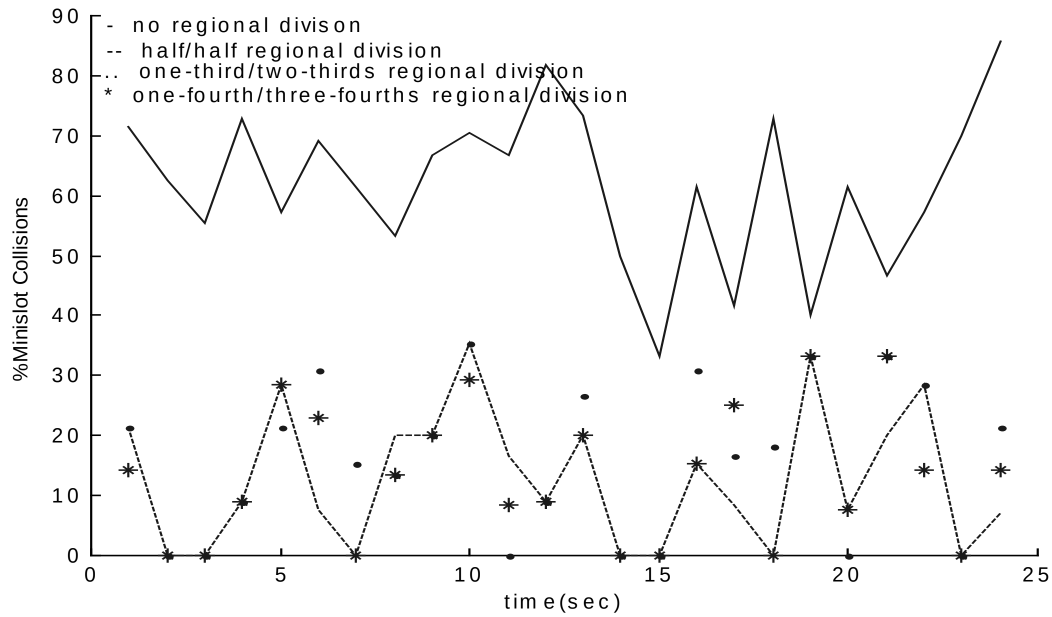

Figure 6. Performance evaluation for regional divisions vs. no regional division.

Earlier we proposed an algorithm that will take into account channel statistics and load conditions for a given period and will check for the optimum division of the network. First, it will create a square matrix of the contending stations from the network. Next, it will divide up the network into two optimum regions traversing upon all possible equal divisions. Then, it will take each segment and divide it further until it reaches the time limit or the physical limit. Finally, it will try to combine the small regions to achieve the ratios that will yield the optimum network within a given time period or feasible network. Figure 7 shows the algorithm. This algorithm serves as a foundation for the MAPF supported MAC protocol to be developed. However, as this algorithm divides and merges the network until the most optimum cluster boundaries were drawn (starting with smaller number of choices and clusters and then sub-clustering and merging), it is infeasible due to the amount of time necessary to get the feedback. Thus, even though 100% efficiency may be achieved with this algorithm (assuming adjacency ordering constraint in the matrix), quicker means to form the clusters need to be found and optimization parameters with their equilibrium (maximum efficiency) points need to be investigated for the final protocol.

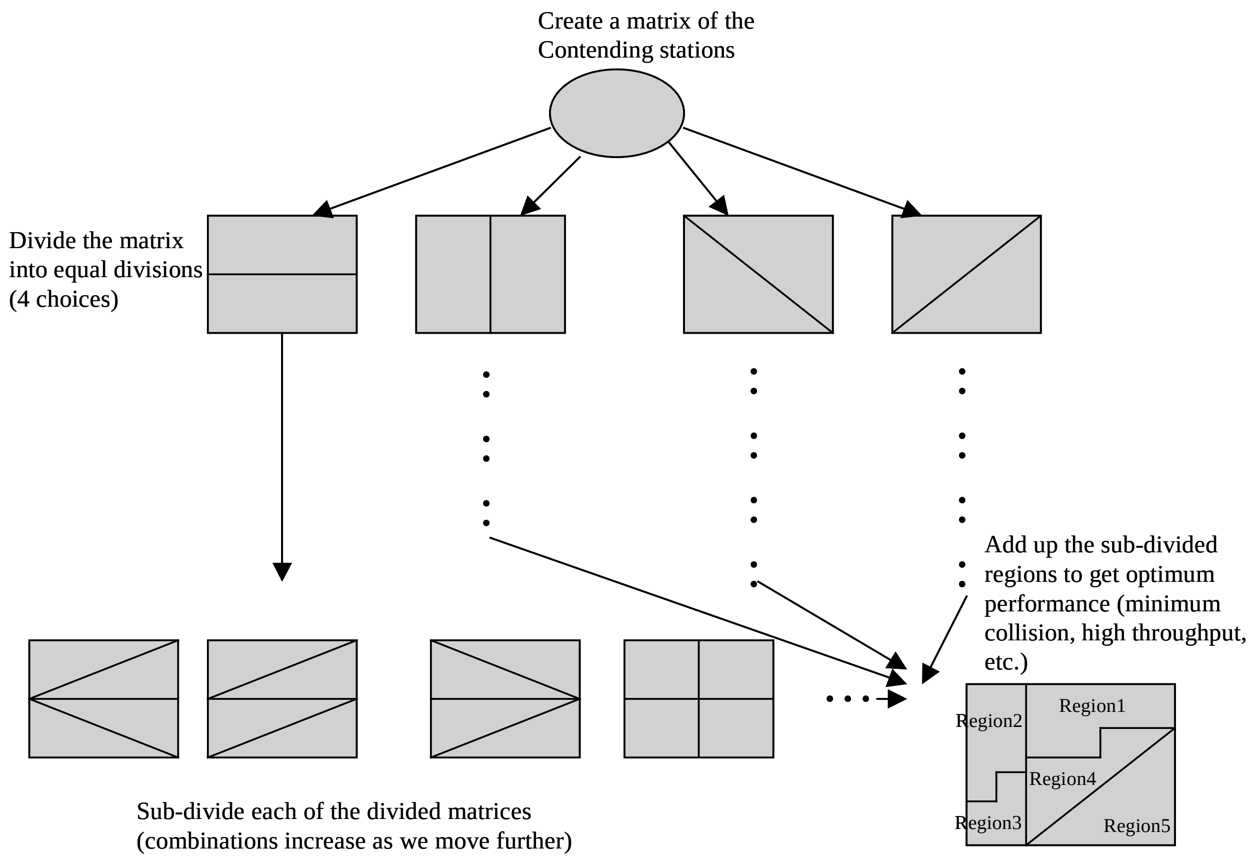

Figure 7. A primarily proposed algorithm to meet DOCSIS QoS objectives and reduce collision.

1.2.5 The Simulation Approach and Environment

This section discusses the simulation approach and environment in three steps. First, it briefs about the single traffic sources used in each SE. Then, it discusses the simulation tool and environment. Finally, it imparts a complete description of the simulation approach.

Although, traffic sources such as Poisson or Markov are amenable and widespread in use, they do not depict the true characteristics of traffic generators. Neither do they take into account the user interaction with the system. These optimistic traffic models thus terribly affect the results from a simulation [25]. We have developed a model that could generate a Poisson or Markov distribution that would not have these inadequacies. To create such a well-behaved traffic model, the first step is to extract network parameters such as probability of ON-OFF duration, expected number of ON-OFF for a given amount of time to model a Markov source, or similar parameters for a Poisson process. From these probabilistic and statistical models we have generated our desired model by using Bayes' estimation, i.e. $p^k(1-p)^{n-k}$ where p is the given probability of an ON/OFF event for Markov. k and n are the number of occurrences of the ON/OFF event chosen for the given p and the total number of occurrences of ON/OFF events, respectively. We simply generate a Poisson traffic distribution to apply Bayes' estimation along with channel upper or lower bounds. These new models give us the advantage to incorporate user activities by means of their duration expectation and expected number of users at a given

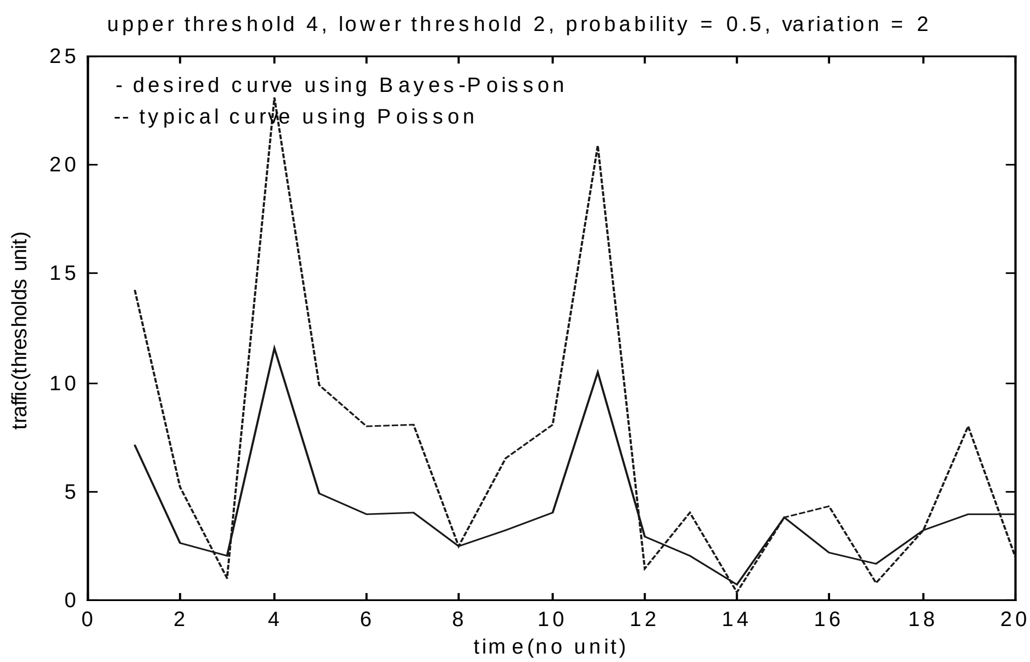

Figure 8. Comparison between the Poisson model and our Bayes-Poisson simulation model.

time of the day. Figure 8 shows the comparison between a Poisson model generated in the traditional way and the Bayes-Poisson model generated using our process. Notice that, the first curve is unpredictable where the second one stays well within the defined upper and lower threshold for most of the time for the given probability and variation.

Though common, OPNET and ns simulators are programmatically comprehensive and less easily modifiable. So, we chose MATLAB for our simulation and created a simulator with user interface that is easily adaptable. Being a user friendly software, MATLAB, with the on-line help menu and easy programming and testing interface, allowed us to test all possible variations within the DOCSIS framework. This allows for a complete collection of statistics on the channel and performance metrics. It is quite problematic to work with the other simulators that do not allow single and aggregated statistics collection flexibilities as multiple layer operations embedded with the standard software package for those simulators makes it very time consuming, impossible, and inefficient to run such simulations. The study of the system architecture and the operation model, which is very important to construct the protocol from the MAPF and analyze it, is also easier when the system can be break into peaces as the proposed simulator does. However, although the simulator allows controlling and monitoring capabilities, real device constraints are applied and collision and randomness in the channel are left uncontrolled by the simulator. Thus, the protocol performance, although evaluated only on a channel access over the MAC layer basis, gives highly realistic performance measures.

The simulator characterizes the traffic at a single SE node as empty, waiting, or transmitting. It also keeps track of the queue at each node and times the waiting period for all the requests that has been generated during the simulation period. When a SE has new data that cannot be piggybacked, it generates a RR message and sends it over the UC to the BS for bandwidth reservation in the UC. If there is no other requests send to that particular CMS by any other SE, the request packet reaches the BS. The ack/grant mechanism is assumed automatic for each request transmitted via the DC to the SE that generated it. There is, however, delay associated with the ack/grant message reception by the corresponding SE depending on whether there are available buffer capacity in the channel for the particular service (voice, video, or internet) requested by the SE. This grant-delay is included in the efficiency calculation as (for these systems) data packets start leaving SE through the UC immediately (and only) after receiving the grant. The simulation process drops traffic off the queue for outdated requests and accounts for them as well. Thus, the simulator realizes the centralized control by aggregating the independent SE flows and analyzing them with respect to the channel capacity and current network load condition. The simulator can monitor each SE along with the whole channel in this way. The buffers for variable services are also maintained during the operation by regularly filling, emptying, and monitoring them. A buffer gets filled when capacity requests for that particular service are granted for the next upstream (remember, we only consider the upstream case as settled before). Similarly, the buffers start to be emptied when the amount of requests for bandwidth drops and the old requests are serviced properly. Finally, the performance metrics are monitored directly for each SE and then aggregated and averaged. These statistics does not need to be finalized in conjunction to the results obtained by monitoring the BS over the UC link since it covers all the SEs. Both the aggregated and averaged statistics are reported.

2 The Proposed Research, Remaining Work, and Facilities Needed

2.1 The Proposed Research

The objective of the proposed research is to develop and evaluate a novel and high performance contention and reservation based medium access control (MAC) protocol for wired and wireless communications. The research work will start by improving on existing methods by defining a framework based on the medium access parameters (MAP) identified during the preliminary investigation. The research will continue with determining how to device a protocol to support this framework. This will result in the novel high performance MAC protocol which will then be evaluated and reported.

This research is unique in that it employs the MAP framework (MAPF) to exert more control over the contention access process and reduce its randomness. Randomness in contention access has always been a problem and will continue to be a threat for future generation systems. The research is also unique since it does not use contention resolution or splitting algorithms (CRA) to maintain network stability during operation; thus, avoiding service degradations. The protocol works within the MAPF by more precisely identifying contending users without going through a back off, tree, or p-persistence mechanism. The MAC protocol is thus guaranteed to be high performance due to the deterministic nature provided by the MAPF.

2.2 Work Remaining

MAPF architectures (wired and wireless) need to be used for designing the protocol. Other protocols such as FMAC, which uses SE distribution, need to be studied and investigated for this purpose. FMAC has a single grouping organization that suffers from not exploiting the long-term benefit of changes in active users, which allow adaptive and efficient redistribution (re-clustering) of contention resources. The primary algorithm presented in Section 1.2.4 can be used as a guideline for this development. Tests on networks for characterizing the parameters need to be performed as well. The optimization of parameters with equilibrium (maximum efficiency) characterization will be possible by these network tests. Therefore, quicker means to list the optimal cluster boundaries can be found and optimization parameters with their equilibrium (maximum efficiency) points can be investigated for the final protocol.

Probabilistic equations to predict and model the behavior of this new MAC protocol need to be completed as well. Moreover, applied mathematical and real system level implementation procedure of the protocol must be investigated in more details and specified. Since CRA is avoided, the protocol will tend more to be like the CRDA protocol with the exception of centralized timers as opposed to distributed ones. This protocol needs to be tested for performance with respect to the fundamentals of the contention reservation protocols that operate under DOCSIS specifications. The results will be comparisons obtained by the simulator on metrics such as cumulative delay, delay per-request, aggregated throughput, and collision. Metrics may be developed and presented to analyze how to reach equilibrium or the best performed state. These performance comparisons will be made for the following 3 cases:

- Wired networks with the general MAPF
- Wireless networks with the general MAPF adapted for fixed interference and blocking (assuming sensory data available for the protocol input)
- Wireless networks with the general MAPF adapted for mobile (interactive) interference and blocking (assuming sensory data available for the protocol input)

The details of the protocol and its operation need to be explained on a state-by-state basis. The protocol will thus be tested for each SE traffic and buffer state (local) and the BS or the global state. The protocol description will then provide a complete view from a packets arrival to a SE until its final state.

The DOCSIS simulation architecture needs to be modified to test the new protocol once it is developed. These means simple architecture level change on signaling over the UC channel, frame format, BS-SE handshaking, and scheduling process. Also, the simulator should be tested to avoid oversimplified assumptions so that it strictly follows the guideline provided in this proposal. A detailed description of the simulator and its adapted version will be provided in the future.

The following time table provides an outline of the time required for completion of the project. The expected time for the thesis submission is tentatively sometimes in June 2003.

The Time Table

Periods (Dec. 2002 – June 2003)	Tasks
Dec. 23 – Jan. 23	Investigate other similar MAC protocols and design the MAC protocol
Jan. 24 – Mar. 24	Test and analyze the MAC protocol, MAPF architectures, and optimization processes
Mar. 25 – Apr. 25	Simulate the MAC protocol
Apr. 26 – Thesis submission	Document and unify all the results

2.3 Facilities Needed

The facilities needed for the operation of this research include PCs that have MATLAB installed in them. These facilities are already available in rooms 304, 308, and 310 of the College of Computing building and in my PC. No other facilities will be necessary.

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