ECE 576

FINAL PROJECT REPORT

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Cognitive Network Device

By:

[redacted]

39/40

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May 12, 2005

This is a good concept paper, indicating what should be done (little detail on "how" it can be accomplished.). It has a v. good potential. ~~Paper~~ Perhaps you should explore learning as a way to realize the adaptation process. (Test plan is ~~[illegible]~~ true

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1. Motivation behind the project

The evolution of telecommunication networks has been driven by an inarguable trend towards unification. Initially, separate networks were built to provide communication for different services. The technology used by each of these networks was especially designed for the kind of services provided. However, over the time, it became evident that the provision of a single service over a whole network leads to the waste of very valuable resources. Hence, a tremendous amount of effort has been done to provide multiple services over a single network. We can see today data being transmitted over traditional phone lines at a speed that was unimaginable only a few years ago. The evolution of wireless networks has not been much different from this picture. Today we have a number of different networks using different technologies, but providing the same services. The current challenge being faced by the telecommunications community is the integration of these multiple networks into a single seamless network.

To satisfy the requirements imposed by this new technology, the network devices have to be able to handle any kind of technology for all types of signals. This condition has posed a new challenge in the technological evolution of network devices. While some degree of adaptation is modeled into the functionality of each of the layers in the architecture, there is a need to account for the adaptation capabilities of the device as a whole system. This requires the introduction of new functionalities in the architecture.

2. Introduction

The evolution of network devices has been driven by the evolution of telecommunication systems. The end devices in the circuit switching network (PTSN) are relatively simple, with most of the administrative and control tasks being performed by the central offices. The development of a packet switching network raised the need to increase complexity in the end devices, as well as in the intermediate nodes. This development led to the creation of a layered architecture for network devices, which defines the set of protocols to be used during the transmission of information. With the goal of assigning specific tasks to each of the layers two layer architectures were created: OSI (Open Systems Interconnection) and TCP/IP. The last one has become the de-facto standard for most of the current communications systems.

The complexity of the current communication systems has also raised the need to create a mechanism to ensure the performance of the network. The administration of the device and the network is performed by a set of functionalities that reside in the management and control planes. These can be visualized as perpendicular to the layered architecture. Figure 1 shows an example for a CISCO optical router.

As is well known, the two main standardization organizations in the networking community, namely the IETF (Internet Engineering Task Force) and the ITU (International Telecommunication Unit), were created at different times and with different objectives. Nonetheless, the evolution of networks has led these two bodies to study sometimes the same problem from a different perspective. The architecture of the management and control planes of optical networks is a specific example of this situation. The separate efforts have lead to different solutions, but finding a unique standard is becoming more urgent every day. The standardization of the management and control plane architectures will allow the network to be constructed out of devices from multiple vendors, and will determine a minimum set of functionalities to be supported by the devices. A scalable architecture is desired in order to account for future developments and new services to be provided over the network. With these goals in mind, the ITU and the IETF have independently developed their own control plane architectures for optical networks, leading to the ASON and GMPLS models. A third body, the OIF (Optical Internetworking Forum), looks at developing interoperability implementation agreements, and has focused on the interfaces between network and user, and between network domains.

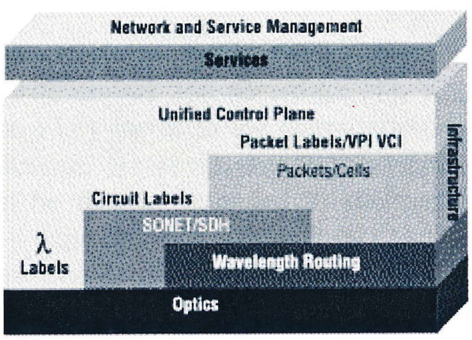

Figure 1. Control Plane at Optical Router

The current trend in networking is towards a unified structure, in which the network device has to be able to handle any kind of technology transmitting any kind of signal. Hence, it is imperative to extend the work that has been done in the optical domain to a context, in which a wider range of technologies can be included. This project shows a possible extension of the current existing architecture, in which intelligence capabilities are added to the devices, so that is able to identified and tune its parameters to the current conditions.

The document is organized as follows: Section 3 presents the problem statement and introduces the proposed solution. Section 4 and 5 present the structural and behavioral models of the system respectively. These two sections constitute the main focus of the project. The goal is to clarify the operation of the system and find the way to integrate it with the existing technologies in network devices. Section 6 presents a possible experimental frame for a specific application. A conclusion section finalizes the document.

3. Problem Statement and Approach

The dynamic nature of the network (e.g., environment, load, and topology) as well as the need to accommodate technology evolution in protocols and devices requires a flexible architecture for the control and management planes. The existing models provide certain degree of flexibility in the domain of optical networks. However, it is important to expand these abilities to other domains and expand the flexibility so that the device can adopt new technologies and new policies can always be reprogrammed.

In other words, the network has to have an adaptation capability. This capability can be achieved by a context (or situation) aware mechanism, which allows the functionalities to be dynamic and active and change according to the situation assessed by a monitoring device residing on the forwarding plane. A context or a situation is defined as any information that can be used to characterize the situation of an entity (in our case the network devices) that is considered relevant to the interaction between network elements or between the network elements and the users. Context or situation awareness is the ability to use context information. A system is situation aware if it can extract, interpret and use the situation information and adapt to the current context [1].

The problem of situation aware networks has been usually studied in the context of cellular wireless [2] and wireless ad hoc networks [1], where the environmental and topology changes constitute a key factor in the degradation of the channels and hence in the performance of the network. However, situation awareness is not limited to these types of networks and can be further extended to the case of optical networks. Even though these networks don't experience environmental changes and the topology changes are very rare, the context awareness can be used to account for optical impairments (for example cumulative dispersion) and determine whether it's necessary to apply a regeneration mechanism to the signals.

The functions required for a network to be context aware are *Extract*, *Use* and *Adapt*. This suggests a layered structure for the awareness. This layered structure has been proposed for the general case of a situation aware network [2], and specified for an Ad-Hoc network [1]. The layered structure, illustrated in Figure 2, consists of three levels, as follows:

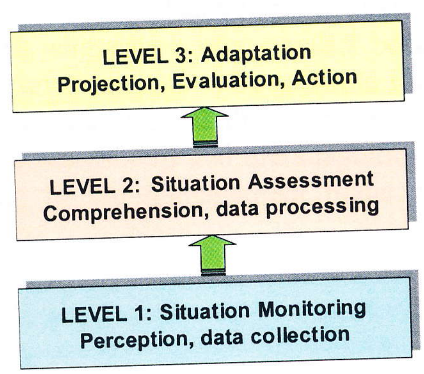

Figure 2. Layered Structure for Situation Awareness

Monitoring: This layer is in charge of collecting the data and reporting the current conditions to the upper layers. It consists of physical sensors, as well as performance counters. The information gathered by the sensors can be classified into four groups [2]: *geographical information*, including location of the node and its neighbors, propagation characteristics of the neighborhood; *spatial information,* such as performance bounds, seasonal variations; *system information,* that includes services offered, impact of perturbations, system load; and *network information* about available capacity, topology and load distribution. The monitoring can be done in two ways: periodically or event triggered. In periodic monitoring data is collected from the network at regular intervals. In event triggered monitoring data is only collected when a change occurs. For event triggered monitoring it is necessary to specify thresholds for triggering events. The monitoring mechanism depends on the specific network device. For example, a periodical monitoring will be more appropriate for a wireless device, whereas the second mechanism would be a more natural choice for an optical device.

Situation Assessment: The goal of this stage is to process the data gathered by the monitoring layer and determine the actions to be taken. The information collected from the different devices has to be processed (e.g., sampled and quantized) in order to be able to make a good inference of the current situation. As with any collection of data, a statistical analysis has to be performed to validate the information. Once the data is validated, a set of possible actions to be taken has to be selected. Each of these actions will have an associated cost and a return value, which will be the parameters in the search for the most appropriate action to be taken.

Adaptation: Once the situation assessment has been completed and the action to be taken identified, the corrective measures have to be implemented. The adaptation layer is responsible for identifying the components and the parameters to be changed. The actions to be performed may involve some times physical components and change parameters such as transmitting power, direction of the antenna, bandwidth, etc. But the actions might also involve changes in policies, or in resource and load allocation.

To implement the three-layer structure proposed for the self-awareness mechanism of the network needs, it needs to be included in the management and control plane architecture analyzed in the previous section. An observation of the awareness layers and the architecture of network devices, suggests a nice parallel between the tow of them that allows the network awareness functionalities to be added to the devices. It is evident that the components performing the functions of the monitoring layer will be part of the forwarding plane. The situation assessment and the adaptation layers, on the other hand, perform actions corresponding to the management plane and the control sub-layer, respectively.

4. Object Model

Before constructing the complete object model of the system, it's useful to look at the functional block representation of the architecture, shown in Figure 3. This figure illustrates the different functionalities residing in each of the planes: management, control and forwarding.

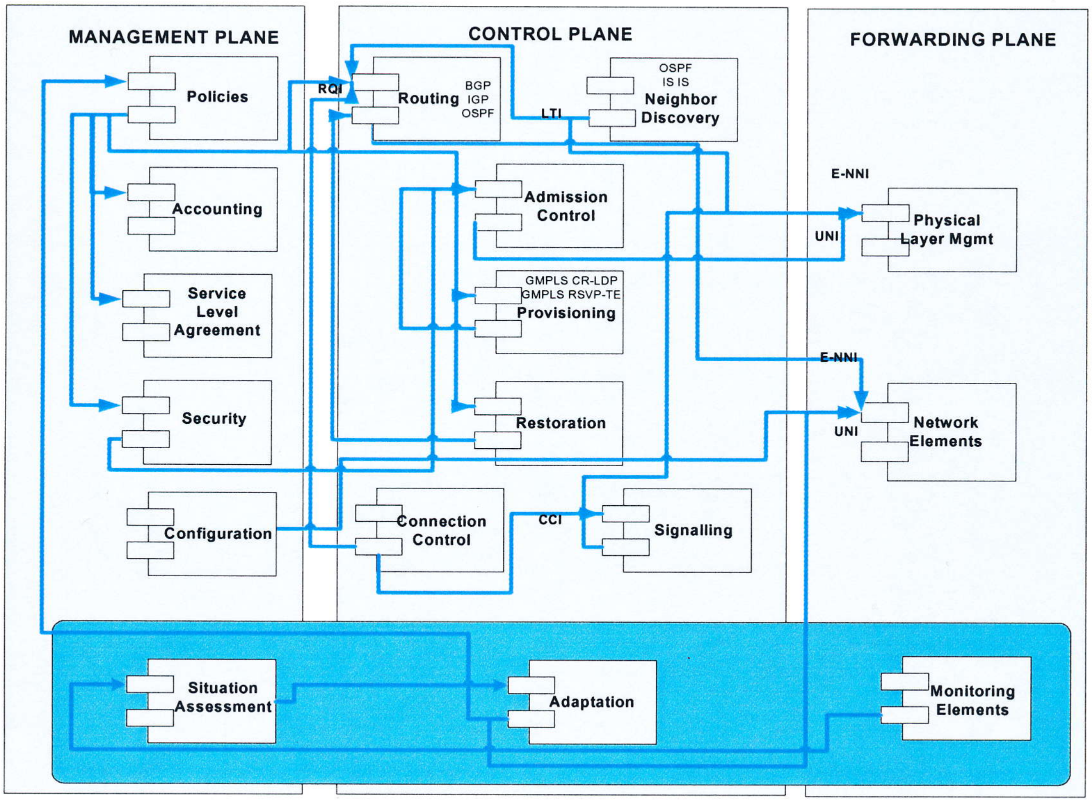

Figure 3. Management and Control Plane Architecture

Based on the figure shown above, the object model is constructed. The top-level view of a network device is shown in Figure 4. Three main components can be identified: Signal Processing Components, Administrative Components and Cognitive Components.

The first set of components refers to the part of the device that performs any operation over the incoming signal, such as digital to analog converters, modulators, demodulators, etc. Part of this set of components, which traditionally was implemented in hardware and was composed of individual physical devices, is currently being implemented in software to add flexibility to the device.

The second set of components, namely the Administrative Components, is in charge of ensuring the proper functioning of the device. Besides performing networking tasks such as admission control and routing, it is also in charge of accounting (when applicable), and service level agreements to guarantee minimum requirements to the users. As seen from the figure two main components form this module: control plane and management plane.

The Cognitive Components module is the innovative part presented in this project. Its purpose is the tuning of different parameters in the signal processing components block to optimize the performance of the device and the network.

The relationships between the main components are illustrated in Figure 4.

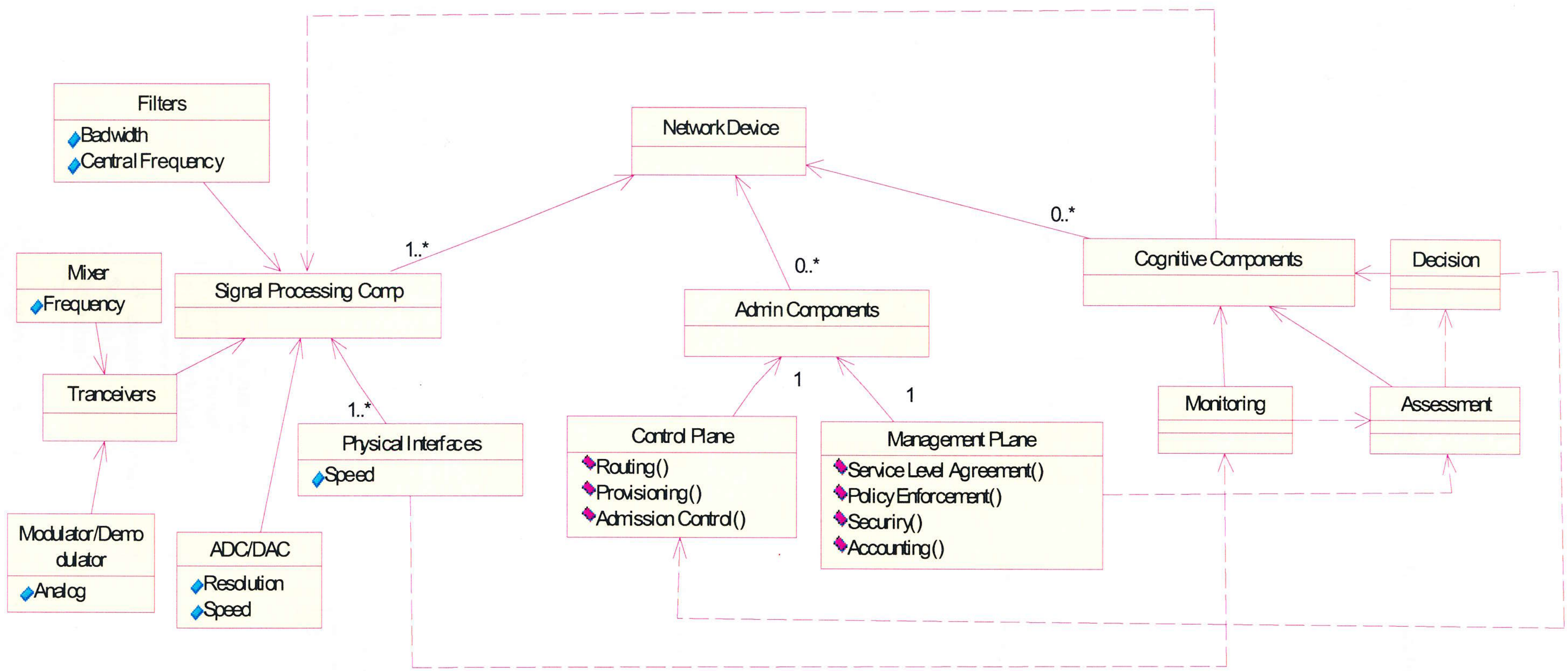

Figure 4. Cognitive Network Device Class Diagram - Top Level View

Figure 5 shows in detail the components of the cognitive module and the relationships between them.

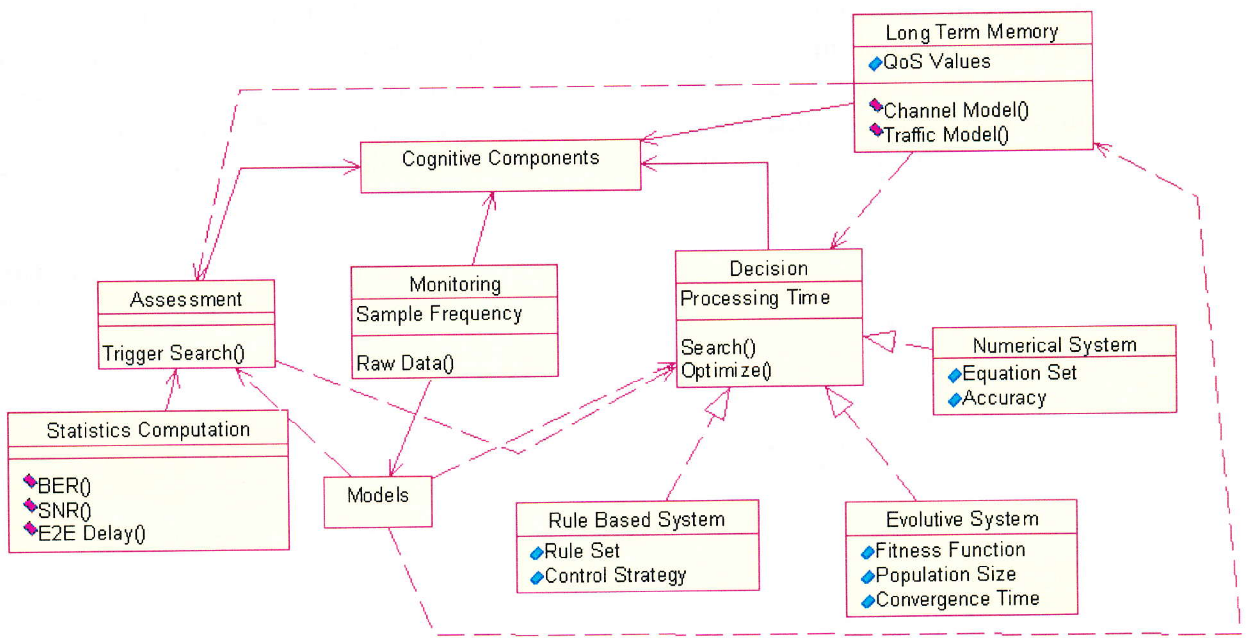

Figure 5. Class Diagram - Cognitive Module

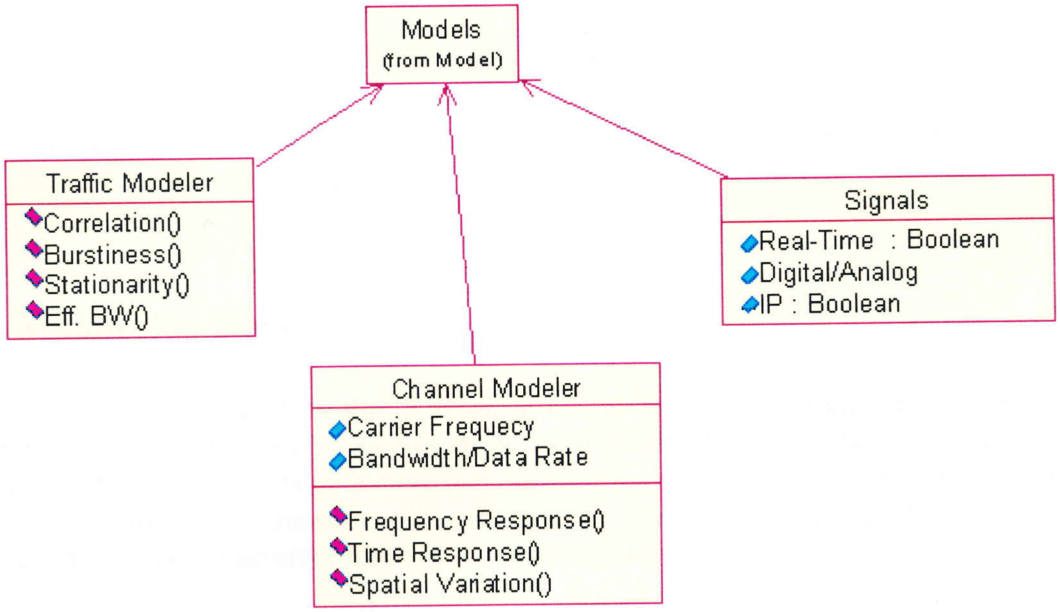

Figure 6. Class Diagram - Models

5. Behavioral Model

The overall behavior of the system is captured in the use case diagram shown in Figure 7. The figure illustrates three main use cases, corresponding to the functionalities of the self-awareness mechanism. It also shows the main actors that participate in the different processes. It can be observed that most of the actors are classes from the object diagram. The use case diagram shows the interaction between the actors (classes) and the functions to be performed. Since the emphasis of this document is on the self awareness part of the device, the behavioral diagrams shown are focused on that part of the system.

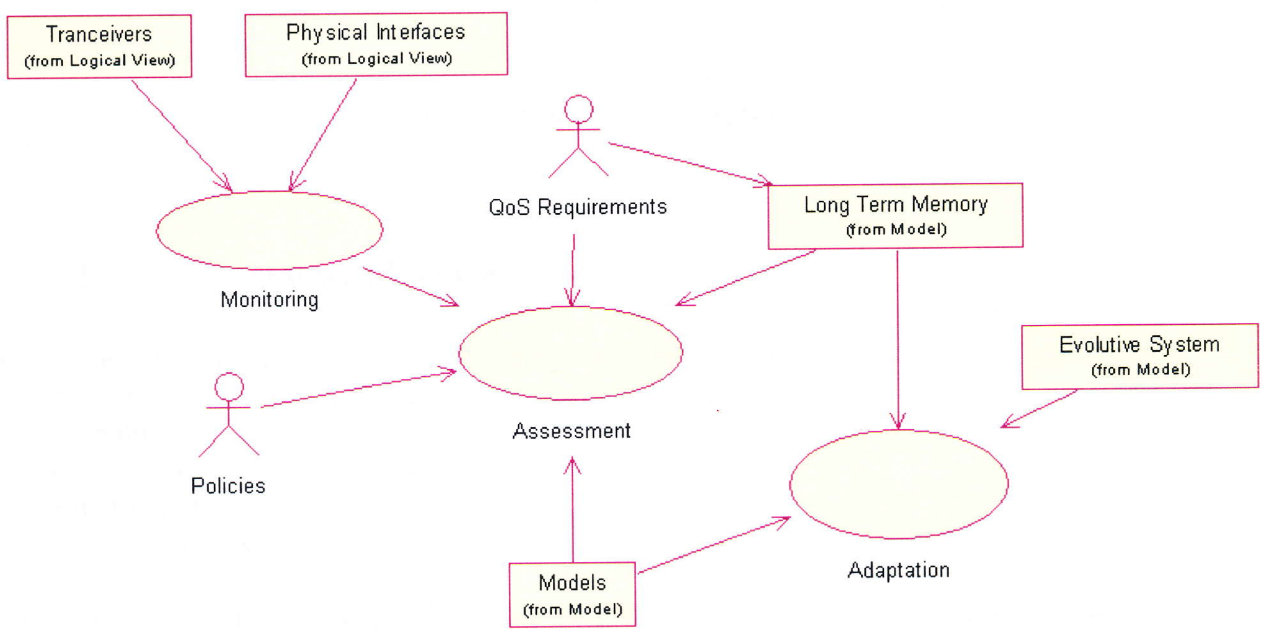

Figure 7. Use Case Diagram

The definition of a complete behavioral model of the system requires a deeper analysis of the behavior of each of the use cases.

5.1. Monitoring Use Case

The main task performed by the monitoring use is the periodical gathering of raw data from the channel. The time between samples is determined by the data rate of the channel, so that a relevant sample is collected, that allows a proper characterization of the channel. The goal is to finally measure the performance, and hence the monitoring use case collects data to compute error rate and end to end delay.

The state diagram corresponding to this use case is relatively simple, and is illustrated in Figure 8.

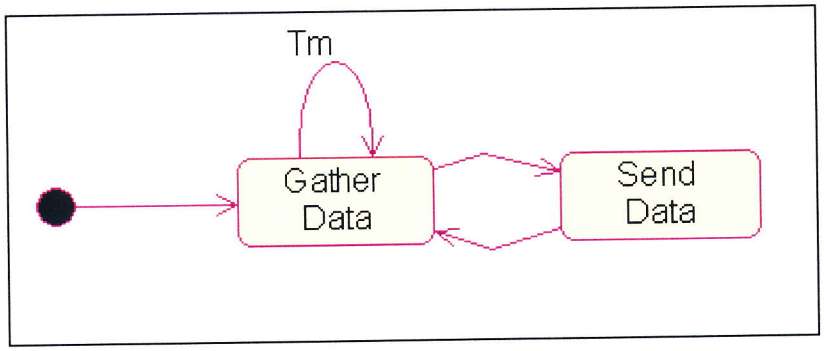

Figure 8. Monitoring State Diagram

5.1. Assessment Use Case

Once the data is gathered by the monitoring layer, the situation assessment is triggered. In this use case, the statistics of the data are computed, such as:

- Probability of Error (BER)
- End-to-End delay
- Hurst parameter
- Correlation Coefficient

The goal in this case is twofold. From one side it's necessary to observe how the channel is performing in order to guarantee a quality of service. On the other hand, it is also necessary to determine the kind of signal being transmitted in order to determine the threshold levels required in terms of the performance parameters. Once the type of signal has been established, the system uses the long term memory to establish the threshold. If the performance is below threshold level, a signal is sent to the adaptation module. This behavior is illustrated by the activity diagram shown in Figure 9.

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It can be noticed from Figure 9 that the activity diagram has a start state, but no end state. This is because the situation assessment is continuously running as long as the device is working. Since a failure can occur at any time, it is important for the situation assessment module to keep track of the channel performance at every moment.

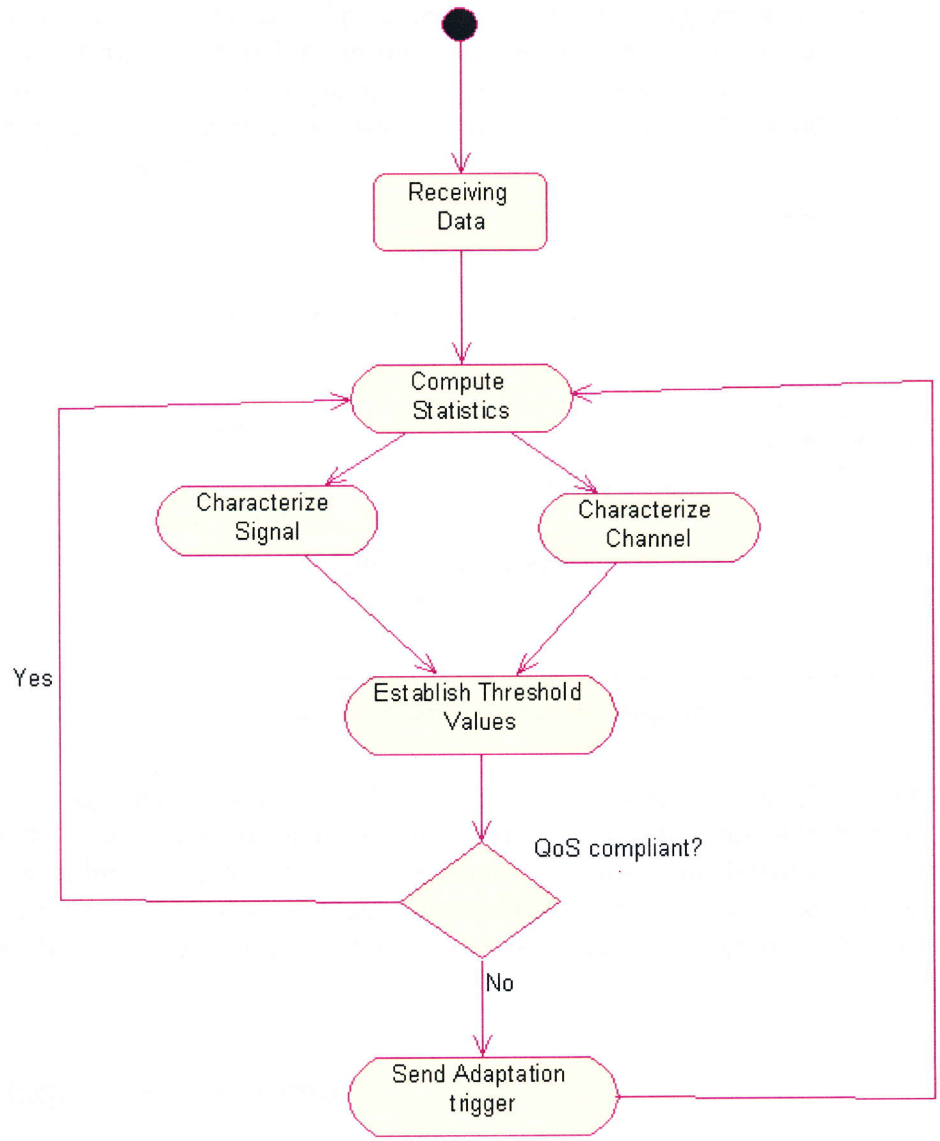

Figure 9. Situation Assessment Activity Diagram

5.2. Adaptation Use Case

Unlike the previous two use cases, the adaptation use case only runs when it is triggered by the situation assessment module, and hence the activity is finished when a better point of operation is found. The goal is to find a set of parameters that improve the current performance of the device within a specified amount of time. This is an important restriction in the field of networking, since the time of response affects the end to end delay, and hence the overall performance of the network.

The problem of finding a better point of operation can be viewed as a search procedure. Since finding the optimal set of parameters can take a long amount of time due to the complexity of the search (which in turns increases with the size of the network and the number of interfaces of the device), the choice it to look for a better performance in an acceptable period. Figure 10 shows an activity diagram for this module. It illustrates a general search process.

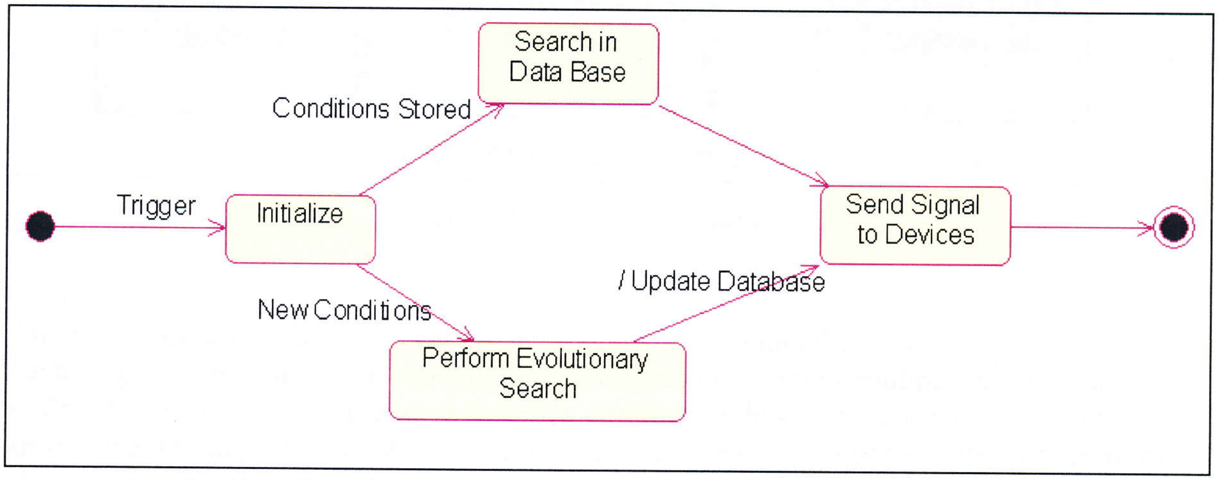

Figure 10. Adaptation Activity Diagram

A complete activity diagram should include the details of the specific search procedure used in the adaptation mechanism. The model proposed is not attached to a specific search algorithm and hence it is not specified by the diagram shown above. However, as part of the research process, different algorithms have been analyzed. The studies have rendered the use of genetic algorithms as the most promising option in terms of response times.

6. Experimental Frame

The complete definition of an experimental frame requires the definition of the main blocks: Generator, Transducer and Acceptor. Illustrates the relationship between the model to be tested and the experimental frame [3].

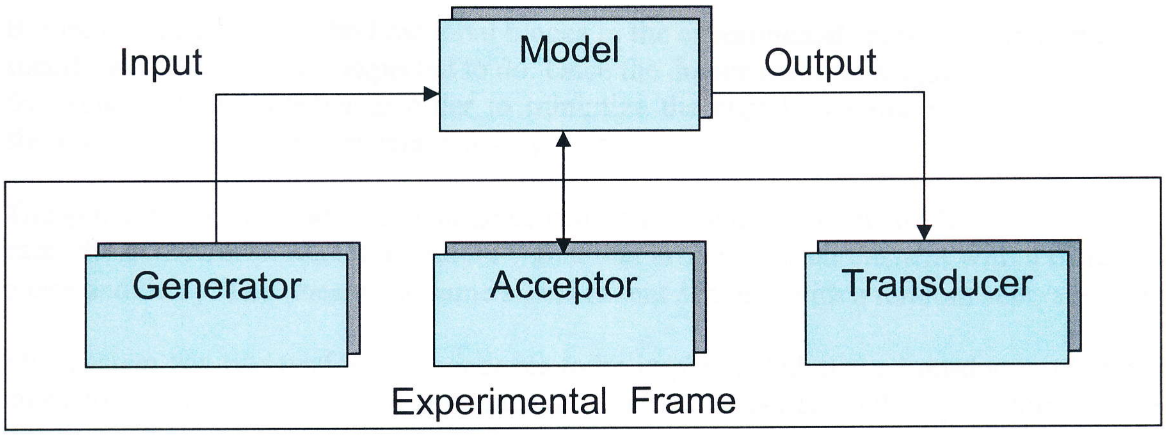

Figure 11. Experimental Frame

The model described so far is very general and can be applied to various specific cases, such as power management, modulation technique, impairment routing, etc. In order to define the experimental frame, a specific application has been chosen, in which the device has to adapt the radiation beam of a set of antennas to optimize the reception of the signal. The system and parameters to optimize are shown in Figure 12. A multi antenna system is shown, in which the orientation and weights assigned to each of the antennas contribute to the receiver's beam. In the figure, $g_i(\theta,\phi)$ and w_i represent the pattern and weight of each element, respectively, y(t) is the received signal and s(t) is the signal at each of the elements.

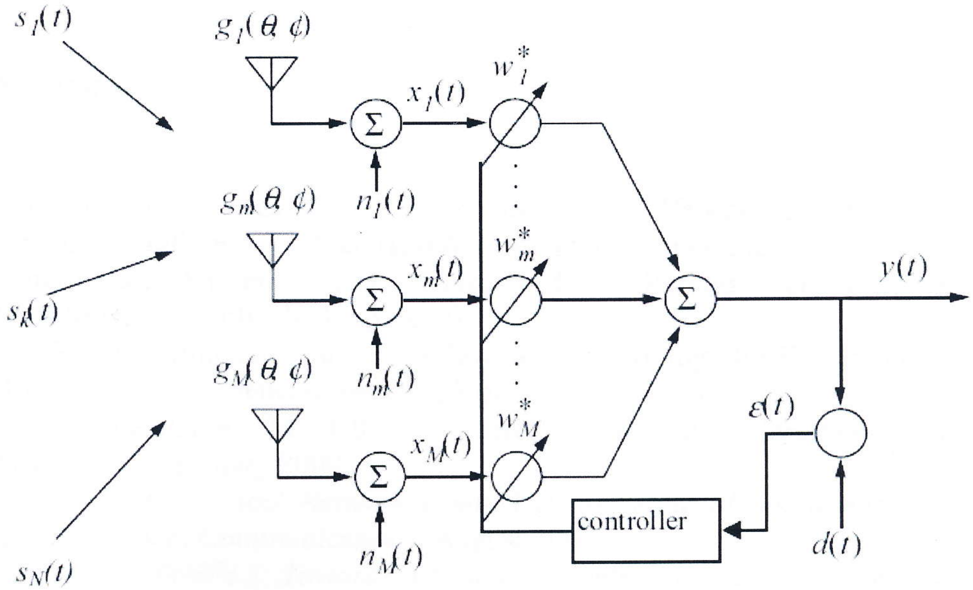

Figure 12. Beam Forming System

Before defining each of the functional blocks in the experimental frame, it is important to specify what the model is expected to do. Once the device receives a signal, it should find the weight of the antenna in order to minimize the signal to noise ratio. The system should find the set of parameters in a very short time.

The generator is the module in charge of generating input segments to the model. In this case, the generator produces a random signal that arrives at each element with a different phase and delay. That means the same signal is sent M times with a random separation Δt.

This system has two performance indexes to be implemented at the transducer: the time taken to adjust the weights of the antennas, and the obtained SNR after adjusting the parameters.

7. Conclusions

This document has presented an approach to introduce cognitive capabilities, absent in today's network devices. The analysis starts with the requirements to build a system with self aware capabilities that can be integrated in the existing architectures for network devices. A three layered mechanism was chosen to implement the self awareness and cognitive capabilities. Based on the management and control plane architectures currently proposed by the standardization bodies in the telecommunication industry, the layered mechanism was embedded into the device and a new architecture was constructed. The structural and behavioral models of the network have been redefined. The top-down approach studied in the class was used in the design of the system and in the integration to the existing technologies.

8. References

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