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CROSS-LAYER DESIGN APPROACH FOR WIRELESS NETWORKS TO IMPROVE THE PERFORMANCE (POSTPRINT)

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14. ABSTRACT
Future wireless networks will be loaded with voice, messaging, file transferring, multimedia teleconferencing, games, and Web browsing. With the increasing traffic and real time demand the current status of networking cannot meet the demands of future wireless applications. Traffic will be jammed on current wireless channels and customers will enter into a deadlock situation. Therefore, new models and approaches are required to meet the customer demands. But, it is a known fact that the available spectrum is sold out and currently used in static mode. Therefore the emergence of next generation wireless technologies will enhance the effectiveness of the existing methods. One of the possible approaches will be allocating the spectrum dynamically by developing new algorithms and protocols. Furthermore, we can eliminate the jamming by using cross-layer approaches. In this research, we discuss the possible ways to eliminate the jamming at node level and meet the customer demands.

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cross layering, transmission communication protocol

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Cross-Layer Design Approach for Wireless Networks to Improve the Performance

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Abstract

Future wireless networks will be loaded with voice, messaging, file transferring, multimedia teleconferencing, games, and Web browsing. With the increasing traffic and real time demand the current status of networking cannot meet the demands of future wireless applications. Traffic will be jammed on current wireless channels and customers will enter into a deadlock situation. Therefore, new models and approaches are required to meet the customer demands. But, it is a known fact that the available spectrum is sold out and currently used in static mode. Therefore the emergence of next generation wireless technologies will enhance the effectiveness of the existing methods. One of the possible approaches will be allocating the spectrum dynamically by developing new algorithms and protocols. Another way is Cross-layer approach which helps in efficient allocation of spectrum to eliminate the jamming problem. In this review, we discuss some of the recent developments in literature on cross-layer aspects and its effect on the allocation of spectrum to meet the customer demands.

Keywords: Cross-layer, open systems interconnection, jamming node, bit error rate, blackboard, critical parameters

1. Introduction

In the early 1980s the International Organization for Standardization (ISO) began to work on an open set of protocols that would enable multivendor computers to interact and communicate with one another. Recently there has been an increased interest among researchers about protocols for wireless networks that rely on significant interactions between various layers of the network stack [1, 4, 5, 6, 12, 14, 15]. The OSI network stack was sought to become the building block of all network based communication worldwide. Overtime, the OSI model has been considered by many to be the ultimate model for worldwide interoperability, however as time has shown, the OSI model has not grown to be nothing but a model that is used to compare other implementations of protocols that would enable multivendor computers to interact and communicate with one another. Recently there has been an increased interest among researchers about protocols for wireless networks that rely on significant interactions between various layers of the network stack [6].

Specifications and interoperability were created to allow others to participate in the network. OSI protocols would have been a good idea to use at that time, but the Internet Protocol (IP) implementation was easy, quick and cheap. IP allowed the Internet to grow rapidly and governments around the world started participating in the Internet growth. IP was expected to be replaced by the OSI protocols, however this never happened. The ISO OSI model still serves today as the reference model by which implementations are compared to and it describes and outlines the different levels of networking protocols and their relationship with each other.

Application Layer
Presentation Layer
Session Layer
Transport layer
Network layer
Data Link Layer
Physical Layer

Figure 1. The OSI reference Model

The Figure 1 displays the OSI 7-layer reference model. The features are common to all approaches in data communications and organize them into layers or modules such that each layer only worries about the layer directly above it and the one directly below it. However, this architecture presents challenges in networks when trying to allocate the available resources among the different network users. The traditional stack approaches main goal was to allow multivendor computers to interact and communicate (transmit pure data traffic), the term Quality of Service (QoS) was not thought of and thus not an issue at the time of the design process. According to [6] the results of the stack design in the OSI is highly rigid and strict, and each layer worries only about the layer directly above it or the one directly below it, which results in a nonexistent collaboration between the different layers, because no-one at the time saw a need for such a feature.

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A recent design principle that allows coordination, interaction, and joint design of protocols crossing different layers appropriately for wireless networks is the Cross Layer Design (CLD) approach. The CLD approach can create loops, but it has been known under Control Theory (CT) that this approach creates some issues under existing conditions. The CLD approach challenges engineers and researchers know about network protocols, layers, and stack design and system construction.

2. Problems in the Current Design

The problems that exist in the current design are due to the fact that the protocols at different layers are designed independently, and each layer is defined in terms of services it offers. The Transmission Control Protocol (TCP), which is typically designed for fixed wired systems also creates problems because of the congestion that sometimes happens because of packet loss. The problems that exist in the wireless networks include: higher bit error rate (BER), multi-signal propagation fading effects, interference problems from other stations and other devices.

In order to solve these problems, TCP needs to depart from its original wired network oriented design as in Figure 2, and evolve to meet the challenges introduced by the wireless portion of the network.

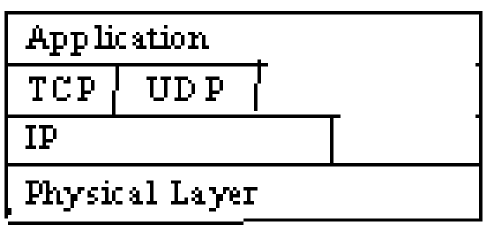

Figure 2. TCP/IP and UDP in a network stack

To meet the wireless portion of the network the researchers currently concentrated at physical layer and data-link layer to speedup the data transfer and power saving [3, 8, 9, 11, 17].

The new approach for efficient data transfer is cognitive networks with cross-layer design approach. But there are some problems in CLD option. The some of the design problems include:

- The CLD is very complex and expensive in the current network models
- Handling critical parameters across the layers at individual node level and network level will be a complex issue
- The role of CLD in cognitive networks for dynamic spectrum allocation is very complex

CLD in the cognitive networks is an interaction interface between non-adjacent nodes to increase the detection rate of the presence of the primary signal. It allows exploring flexibility in the cognitive nodes by using them to enable adaptability and controlling specific features jointly across multiple nodes. The CLD extends the traditional network topology architecture by providing communication between non-adjacent nodes. Hence the CLD design became an important part in relation to flexibility and adaptability of the cognitive network nodes. One of the efficient CLD architecture for cognitive networks includes the following components:

- Cross-layer manager and scheduler of nodes
- Cross-layer interface to nodes
- Cross-layer module of single node
- Inter-node (network) cross-layer module

The CLD using these components needs more care because CLD nodes interact with other CLD which would generate interference. Furthermore, the interaction of CLDs, influences not only the layers concerned, but also the parts of the system. It may be unrelated at the remote site but unintended overhead may effect on the overall performance.

The initial research efforts in the cognitive networks and cross-layer design are seen in the literature [1, 4, 5, 6, 12, 13, 15, 16, 19, 20].

3. Cross-Layer Selection in Wireless Networks

The motivation for the cross layer design approach in wireless networks is due to the fact that wireless links create several new problems for protocol design that cannot be handled well in the framework of the layered architectures. Cross layering is therefore not the simple replacement of a layered architecture, nor is it the simple combination of layered functionality; instead, cross-layering attempts to share information amongst different layers, which can be used as input for algorithms, for decision processes, and adaptations [12]. Wireless mediums offer new modalities of communications that the layered architectures do not accommodate. This opportunity allows for the violation of the layered architectures by the cross layer design [10, 13].

The layered paradigm works poorly in wireless networks due to user/node mobility, limited data transfer performance, low energy efficiency, and the quality of service requirements. In order to fix these problems in the network, [4] suggests a tighter integration among the layers is needed. A particular suggestion to introduce the cross layer could possibly yield an improvement in the throughput or delay performance of the network. But, in order to implement this design efficiently one must consider the potential challenges that the cross layer design presents.

We will outline some of the challenges that the designers proposing cross-layer design ideas:

- Coexistence of different cross-layer design ideas and its reliability
- Can it have significant impact on network performance and solve the current problems including jamming and interference
- Can we invoke the CLD in current environmental conditions?
- Can we standardize the information sharing between layers

There are many similar issues came up in the CLD proposal and we discuss some of the open challenges in the next section.

4. Open Challenges in Cross Layer Design

When incorporating the cross layer design one may incur architectural and design issues [1]. The architectural issues include:

- Interfaces to layers (upward, downward, and both ways): Interfacing the layers help to share the information between the layers (Figure 3 A).
- Merging adjacent layers and making super layers. Merging two or more layers may not require a new interface, but it is suggested that a higher level interface for these merged layers will help to improve the performance with overheads (Figure 3 B).
- Coupling two or more layers without extra layers, improve the performance without an interface. For example, design the MAC layer for uplink of wireless LAN when PHY is capable of providing multiple packet reception capability. This changes the role of MAC layer with new design, but there is no interaction with other layers (sometimes this may hinder the overall performance).
- Tuning the parameters of each layer by looking at the performance of each layer will help more than tuning individual parameters. Joint tuning is more useful in dynamic channel allocation (Figure 3 C).

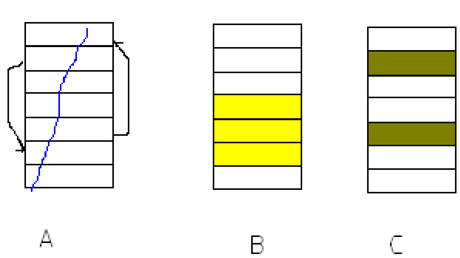

Figure 3. Crosss-Layer Design proposals

Design issues include:

- cost-benefit network implementation of cross-layer (CL) proposals in the current network
- the roles of layers at individual node and global parameter settings of layers
- the role of cross-layer design in the future networks and will this be different in cognitive network design

The network conditions in a wireless network are usually time-varying. Reference [1] suggests that efficient mechanisms be made in order to make a timely and accurate assessment of the state of the network that needs to be built into the stack, and the corresponding overheads must be taken into account.

5. Similar Proposals presented to improve Network Performance

David Clark's [2] knowledge plane proposal with cognitive networks suggests the building of a fundamentally different sort of network that can assemble itself given high level instructions, reassemble itself as requirements change, automatically discover when something goes wrong, and automatically fix a detected problem or explain why it cannot do so using the knowledge plane. Thus, indentifying the problem by combining the data from the edges and inside the network will satisfy the global perspective. Using a compositional structure to merge the unconnected networks in order to connect their activities, and a unified approach to integrate and develop solutions to problems will improve and optimize the performance in the network.

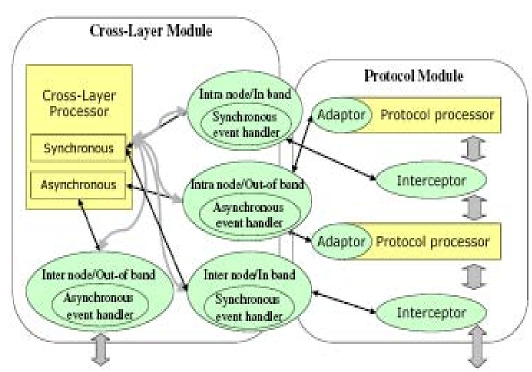

Figure 4. Choi, Perry, and Nettles Software Architecture [16]

But just like this proposal and many others, it fails to take into account the variations and the underlying network conditions. Proposers of the cross-layer design rely on the back-and forth information flow between layers or dynamic vertical calibrations instead of the impact of delays in the retrieval/updating of information on protocol performance. Similarly as shown in Figure 4, Choi, Perry, and Nettles [16] Software Architecture model is less favored because of the back-and-forth design between the layers causes the designer to have to modify each of the layers at the same time thus causing a delay. The inter-module connection involves the interface analyzing information between the layers that will be transferred to one place that processes it, and from there it tries to modify the layers.

In the model proposed by Reddy and Bullmaster [4] as shown in Figure 5, each node is cognitively connected. Each layer works independently so that it does not interfere with the other layers. The interface then collects critical parameters into the cross layer, and then it analyzes the parameters. Whichever critical parameter has a problem, the interface directly extracts and analyzes the problem and deals with the layer without interfering with layer flow which improves the network performance.

By evaluating the ideas of other proposals to create new ideas for improvement of network performance we can eliminate the problems with the cross layer design such as layer flow disturbance, re-writing problems that occur with the protocols, and the delay/ interruptions that occur when using any cross layer approach.

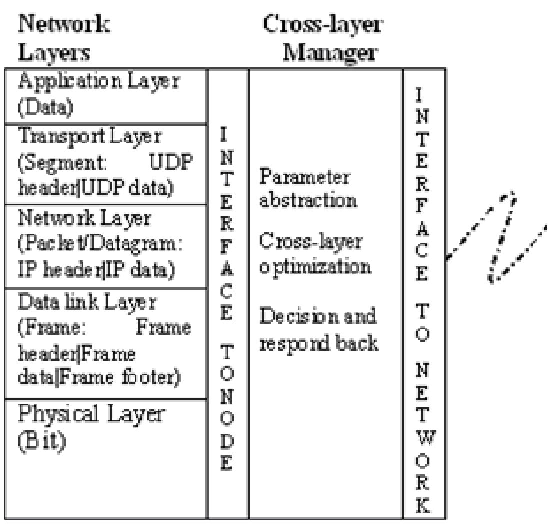

Figure 5. Cross-layer design at Cognitive Node

6. Cross Layer Management of Cognitive Networks

To solve the future cognitive networks [9, 3, 8, 11] jamming problem we suggest incorporating the blackboard architecture model. The blackboard is a centralized global data structure consisting of a set of knowledge sources called intelligent agents (cognitive nodes). The cognitive nodes (agents) are self sufficient intelligent nodes that interact with the blackboard, write the necessary information (critical parameters) to the blackboard and further provide updates with the current state of information available from the blackboard. The design allows for an opportunistic control strategy. The opportunistic control problem solving technique allows the node (knowledge source or intelligent agent) to contribute towards the solution of the current problem without knowing what other sources use the information. The opportunistic problem solving allows the blackboard control structure and scheduler to determine which knowledge sources are active at a given time.

The class-layer manager of each cognitive node processes, generates critical parameters, and communicates to blackboard through the network interface. The parameters provide current network state information and network behavior across the composite end-to-end communications path (irregular patterns in network or intrusions, overlays, and path status), hop behavior (e. g. transmission characteristics) in a manner that attempts to counter the effects of changing channel, and bandwidth utilization.

The suggested blackboard architecture has the messages communicated from the cognitive nodes through a node communication language (NCL). The cognitive node generated messages must be simple and easy to parse. The NCL can be derived from extended markup language (XML), user generated macros using one of the languages (C, C++, and Java), or use quarry language (SQL). The cognitive node messages can include the node position and status, irregular patterns, transmission characteristics, status of bandwidth utilization, and similar parameters.

The design of blackboard for cognitive wireless networks was suggested in [4]. The blackboard integrates various knowledge sources (cognitive nodes) around a central data structure known as the working space. The purpose will be served if we can achieve the controlling strategy and real-time performance. Figure 6 depicts the blackboard architecture for cognitive networks.

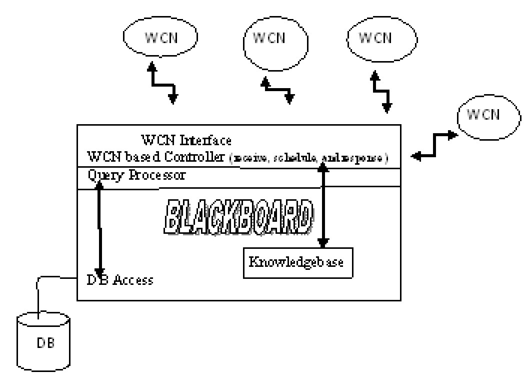

Figure 6. Blackboard Architecture

Wireless cognitive node (WCN) interface connects the cognitive nodes and blackboard. The controller receives the messages, schedules messages, and conducts appropriate actions. The controller interacts with knowledgebase and query processor to process the messages in the form of queries. The knowledgebase consists of set of production rules and inference engine to operate those rules. The workspace is part of the blackboard (not shown in the Figure 5) and stores the messages generated by the agents.

7. Future Research

The research in cross-layer design and implementation is in its primitive stage. Many wireless industries are trying to incorporate at some level of cross-layer design for power saving and solving the jamming problems. More research is needed before any successful attempt of cross-layer design can be completed. The references [9, 17-20] provide the recent work on cross-layer design and cognitive networks.

Our current research involves the game theory models to cross-layer approach for efficient utilization of spectrum and power saving.

8. Conclusions

By taking a look at the current activities of research in the area of cross layer design, we are able to bring different interpretations of cross-layer design together and survey the ongoing work by creating a representative approach to enhance the findings of a solution to the enhancement of wireless networks by using this cross-layer design technique. By looking at the initial ideas for implementing cross-layer techniques, looking at the challenges faced, and the problems that occur, similar proposals to opportunistically use the cross-layer design technique, we also point out some ideas in this area to enhance the architecture of the cross-layer design approach to improve the performance of networks overall. Furthermore, we have summarized the current state of knowledge in the area of CLD and proposed a platform for future research in CLD.

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Cross-layer Design Approach for Wireless Networks to Improve the Performance

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Abstract

- Future wireless networks will be loaded with voice, messaging, file transferring, multimedia teleconferencing, games, and Web browsing. With the increasing traffic and real time demand the current status of networking can not meet the demands of future wireless applications. Traffic will be jammed on current wireless channels and customers will enter into a deadlock situation. Therefore, new models and approaches are required to meet the customer demands. But, it is a known fact that the available spectrum is sold out and currently used in static mode. Therefore the emergence of next generation wireless technologies will enhance the effectiveness of the existing methods. One of the possible approaches will be allocating the spectrum dynamically by developing new algorithms and protocols. Furthermore, we can eliminate the jamming by using cross-layer approaches. In this research, we discuss the possible ways to eliminate the jamming at node level and meet the customer demands.

Research Focus

- **Layering and Cross-layering**
- **Provide Current Status of Cross-layer Design in cognitive net performance improvement**
- **Focus on Cross-layer approach to represent suitable design framework**
- **Architecture for better performance**

Layering and Cross-layering

- standardized layered architecture is called open systems implementation (OSI)
- Transmission communication protocol (TCP) is a transport (layer 4) protocol that uses the basic Internet protocol (IP) services to provide applications with an end-to-end connection-oriented packet transport mechanism that ensures the reliable and ordered delivery of data
- TCP/IP protocol follows the OSI guidelines and designed for point-to-point communication in wire-line communication systems
- Layering enable fast development of interoperable systems
- Limited performance of the overall architecture, due to the lack of coordination among protocols
- Cross-layering is a recent design principle that allow coordination, interaction and joint design of protocols crossing different layers appropriate for wireless networks

Problems in current design

- Protocols at different layers designed independently
- Each layer is defined in terms of services it offers
- TCP typically designed for fixed wired systems.
- In TCP, the packet loss may happen due to congestion
- The problems in wireless networks include, higher bit error rate (BER), multi signal propagation fading effects, interference problems from other stations, and other devices

What is needed

- To solve these problems, TCP needs to depart from its original wired network oriented design and evolve to meet the challenges introduced by the wireless portion of the network

Cross-Layer Selection in Wireless

Layered paradigm works poorly in Wireless networks, du to:

- User/Node mobility
- Limited data transfer performance
- Low energy efficiency
- Quality of service requirements

What is needed

- Tighter integration among the layers is required

Problems in Cross-layer design

Architectural violations if we do the following

- create Interfaces to layers (up-down or both ways)
- merging layers and creating interfaces
- coupling two or more layers
- Tuning the parameters of each layer by analyzing the performance at each layer

Design Issues

- Cost-benefit network implementations
- Roles of layers at individual node and global parameter settings of layers

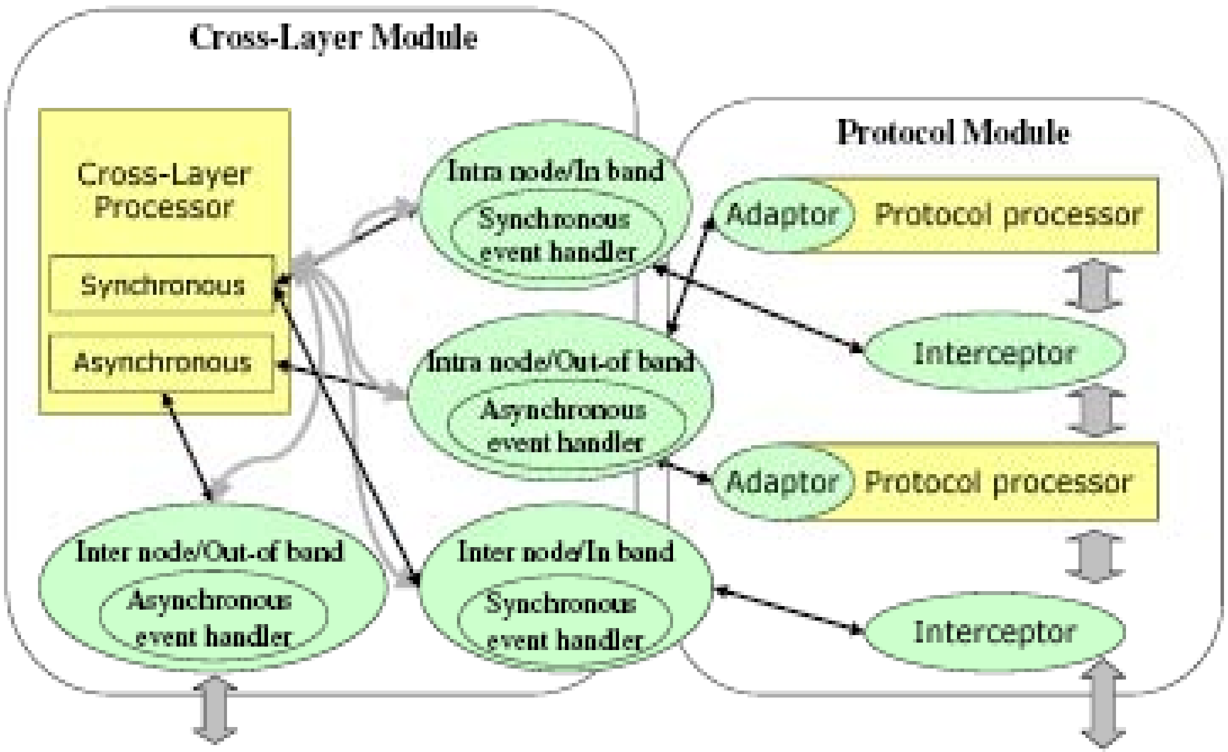
Similar Proposals

David Clark’s Knowledge plane – Cognitive Networks

- Edge involvement – knowledge generated by devices and applications that use it will be brought to the plane
- Global Perspective – The problem identification depends upon the combination of data from the edges and inside network.
- Compositional structure – merging of unconnected networks to connect their activities
- Unified approach – integrated approach to develop solutions to problems
- Cognitive framework – to take decisions based on partial or full information

Similar Proposals

Choi, Perry, and Nettles Software Architecture



Similar Proposals

Reddy and Bullmaster Cognitive Node Level Architecture

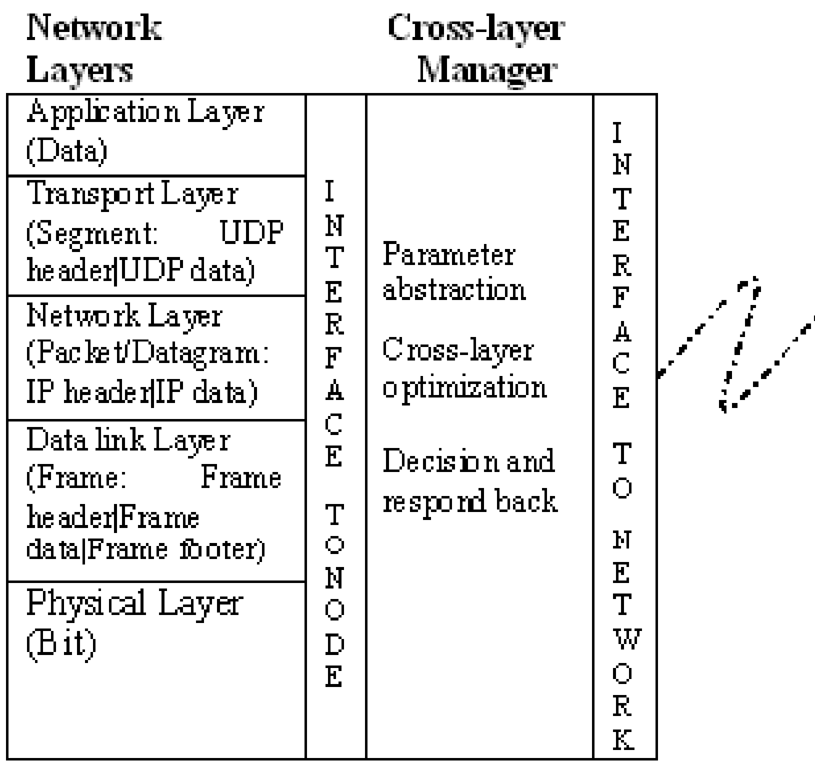
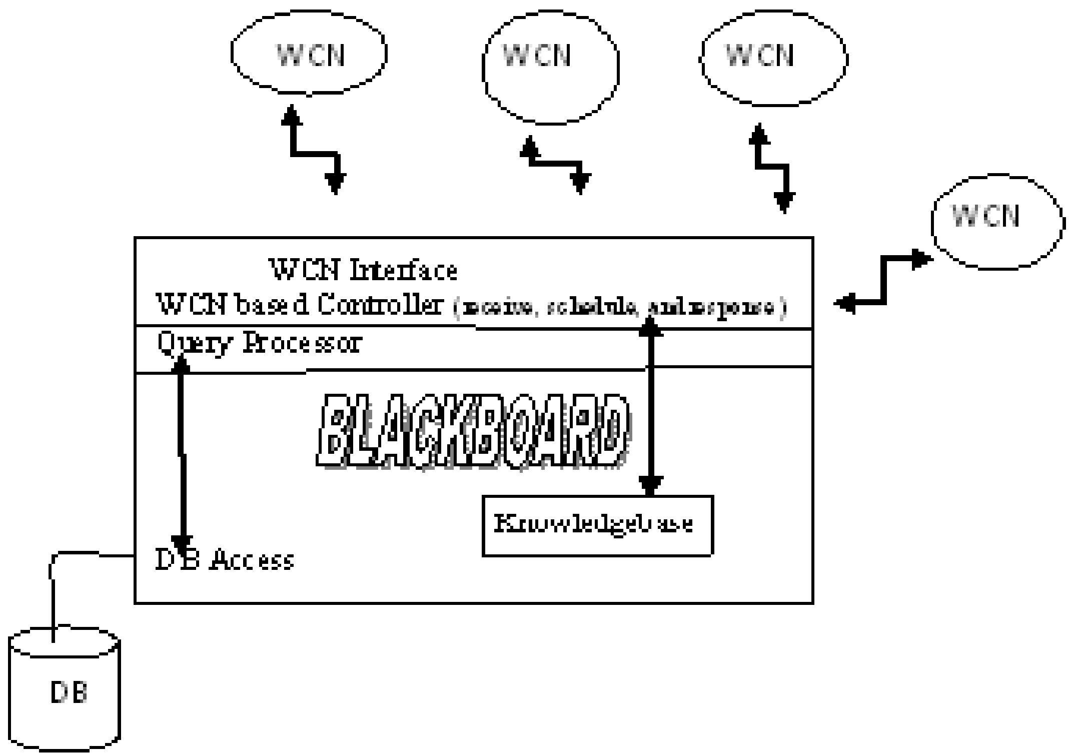


Figure 1: Cross-layer design at Cognitive Node

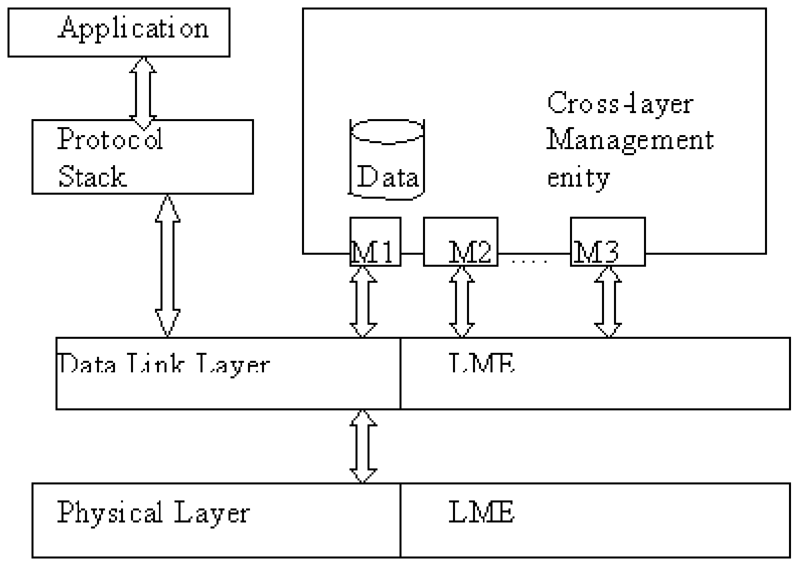
Similar Proposals

Reddy and Bullmaster Cognitive Network Architecture for Cross-layer Design-Blackboard Architecture



Similar Proposals

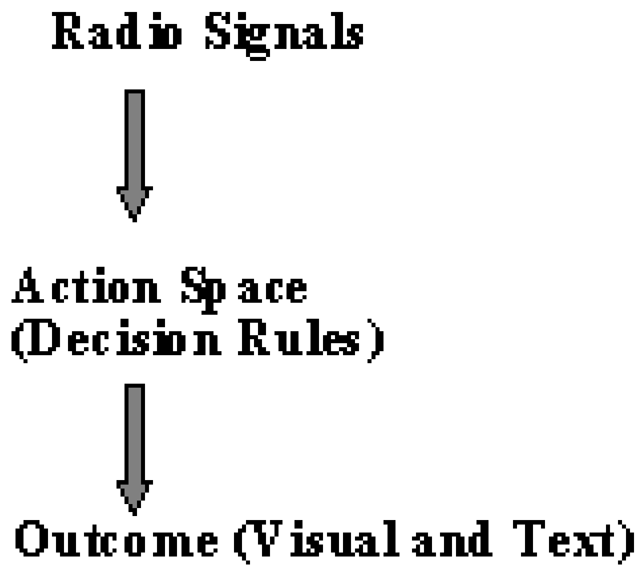
Zho and Sun Cross-layer Horizontal Architecture for Wireless Sensor Networks



Cross-layer management entity divided into two parts:
Management entity and data Structure

The task of cross layer management entity includes providing optimal data transmission routines, moving the node into power saving mode whenever feasible, physical layer coding and data structure sharing

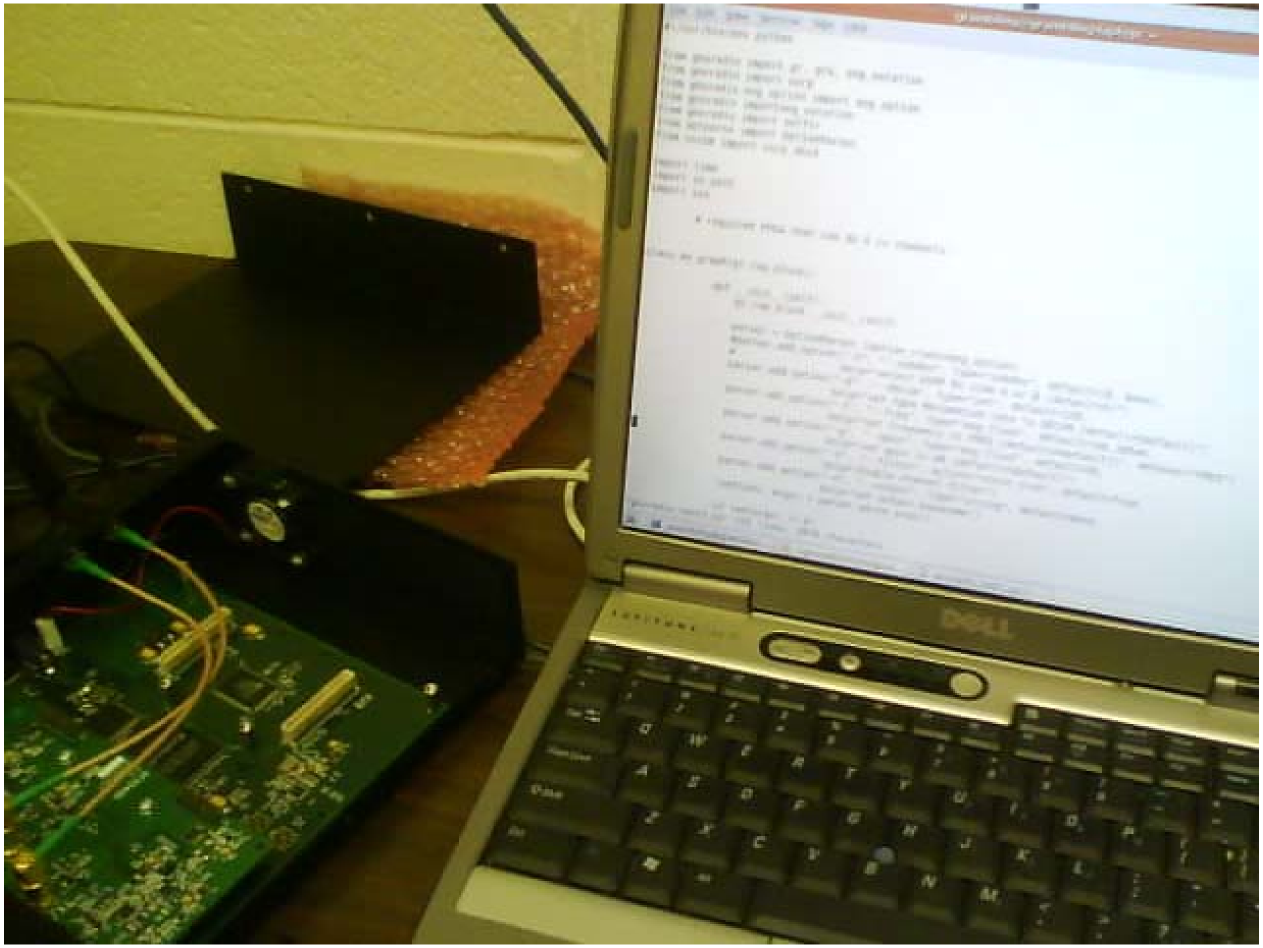
Proposed Method to extract signal Analysis



Infer type of signals
Register frequencies, modulations, power levels, antenna Choice

The radios implement actions and observe outcomes
They try to maximize signal to Interference Ratio

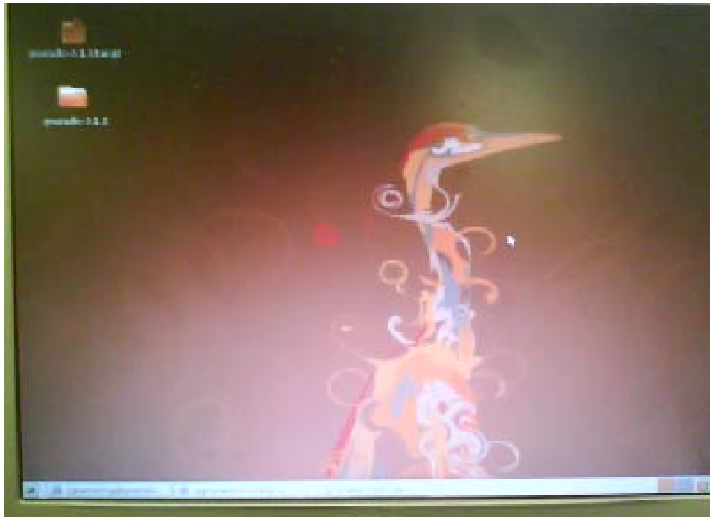
Cognitive Radio Setup



Current Status

- Built and installed software for Cognitive Radio using a University administered test laptop.

- Loaded GNU Radio build and tested it on a windows based platform. After several attempts to configure the system without any errors, we decided to try another compatible software platform, LINUX (Ubuntu).



Current Status

- We formatted the laptop and reconfigured it to meet the requirements of the GNU Radio installation using Ubuntu.
- We are currently testing sample Python codes to build a connection between the cognitive radio transmitter and the GNU software.
- We are also using MATLAB as our database to make charts and output data received from the cognitive radio transmitter.

Conclusions

- **Cross-layer is a promising technology for efficient resource utilization**
- **There are problems in Cross-layer design and implementation**
- **Introduced various proposals for cross-layer implementation**
- **Proposed new architecture for Cross-layer**
- **Appropriate introduction of cross-layer approach helps coordination, interaction, and joint design of protocols for crossing different layers**
- **Cross-layer improves node mobility, quality of service, and energy efficiency**

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