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Adaptive Scalable Cross Layer Framework for Multi-hop Wireless Sensor Networks

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***Abstract*—The role of the sensor network from simply a means for communication to a technology that can be engineered to improve structural assessment through the interaction of sub-networks fusing data from distributed, heterogeneous sensor arrays. The multi-scale network concept introduced here helps to improve power efficiency, minimize packet loss, latency and eliminate synchronization issues through the use of a decentralized analysis scheme and the activation of sub-networks only in the vicinity of suspected damage. A security mechanism for one layer cannot protect the other layer. Hence cross layer security mechanisms are indeed necessary to protect these large scale multi-hop wireless networks from passive, active and denial of service attacks. In this paper I analyze the performance improvement of multi-hop routing scalability with the localization support and the consequent risks of a cross-layer approach.**

***Index Terms*—Multi-Scale WSN, Heterogeneous Sensor Arrays, Cross Layer Security Mechanism, Multi-Hop Wireless Networks, Routing Scalability, Localization Support.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) represent a new generation of distributed systems to support a broad range of applications. A WSN consists of a large number of microsensors which are typically powered by small energy-constrained batteries. In many application scenarios, these batteries can not be replaced or recharged, making the sensor useless once battery life is over. Thus, minimizing the total energy consumption (i.e., circuits and signal transmission energies) is a critical factor in designing a WSN. In sensor networks, nodes are deployed into an infrastructure free environment. Without any a priori information about the network topology or the global, even local view, sensor nodes must self-configure and gradually establish the network infrastructure from the scratch during the initialization phase. With the support of this infrastructure, nodes are able to accept queries from remote sites, interact with the physical environment, actuate in response to the sensor readings, and relay sensed information through the multi-hop sensor networks.

A. The Need for Adaptive Scalable Cross Layer Framework

In existing cross-layer approaches, the violation of the OSI architecture typically consists in passing information between different adjacent or non-adjacent layers of one single station's protocol stack to solve an optimization problem and exploiting the dependencies between the

I propose to go a step further and to consider cross-layer information exchange across different layers of multiple stations involved in multi-hop communication systems. In this work, we adopt a cross-layer strategy that considers routing and MAC layers jointly. At the routing layer, we propose balancing the traffic through the WSN. We show that sending the traffic generated by each sensor node through multiple paths instead of using a single path allows significant energy conservation. On the other hand, at the MAC layer, we propose to control the retry limit of retransmissions over each wireless link. We show that by efficiently adjusting the retry limit for each link, further energy conservation can be achieved, improving thus the network lifetime. A new analytical model for the joint optimization system is complemented by simulations in order to quantitatively evaluate the benefits of energy consumption and latency.

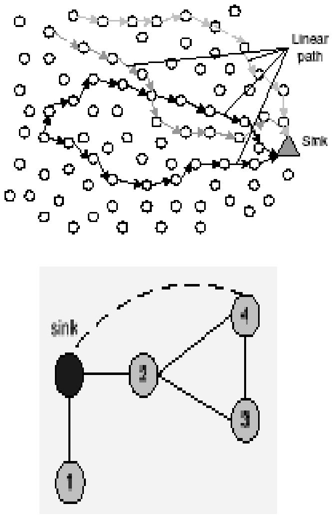

Figure1: Simple Linear Sensor Network

Devices in sensor networks have a much smaller memory, constrained energy supply, less process and communication bandwidth. Topologies of the sensor networks are constantly changing due to a high node failure rate, occasional shutdown and abrupt communication interferences. Due to the nature of the applications supported, sensor networks need to be densely deployed and have anywhere from thousands to millions of sensing devices, which are the orders of magnitude larger than traditional ad hoc mobile networks. In fact, since the output transmission energy is dependent to the distance between transmitter and receiver, long distance wireless communication systems use efficient protocols (emphasizing on modulation schemes) to minimize the output transmission energy.

Several energy-efficient approaches have been investigated for different layers of a WSN. Central to the

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study of energy-efficient techniques in physical layer of a WSN is modulation. Since, achieving all requirements (e.g., minimum energy consumption, maximum bandwidth efficiency, high system performance and low complexity) are a complex task in a WSN and due to the power limitation in sensor nodes, the choice of a proper modulation scheme is a main challenge in designing a WSN. Taking this into account, an energy-efficient modulation scheme should be simple enough to be implemented by state-of-the-art low-power technology, but still robust enough to provide the desired service.

Without a scalable routing service, broadcast storms caused by the route discovery may result in significant power consumption and possibly a network meltdown. Without a real-time communication service, applications cannot react to the changes of the environment quickly enough to be effective. Without efficient energy-aware design, nodes in the sensor networks could deplete themselves after only several rounds of burst activities. Without fault-tolerance and self-stabilization supports in such a dynamic and faulty system, sensor networks could never converge and are unable to guarantee an effective transport service to the applications.

We do not close the eyes to the importance of the killer applications, but we argue that without a new network architecture tailored to the characteristics of sensor networks, the popularity of sensor networks cannot be a reality in the near future. So I propose an adaptive scalable wsn framework that standardizes and stabilizes cross layer interactions, necessary to sustain further development of this field. In fact, multi-scale modular cross-layering supports protocols that can save a great deal of energy to support service to the end user for longer periods of time.

B. Motivation towards Adaptive Scalable Framework

An adaptive autonomic scalable computing initiative provides products that are self-configuring, self-optimizing, and self-protecting, as well as self-healing. Our goal is similar: to build sensor networks that have the ability to self-configure to suit varying and possibly unpredictable conditions, constantly monitor itself for optimal functioning, be able to find alternate ways to function when it encounters problems, and be able to adapt to environmental conditions. The main aims drives by this research paper are:-

- Flexibility through energy-efficient modulation scheme with adaptive cross-layer protocol design.
- Large Scale & Multihop Routing scalability with the localization support.
- Self-stabilization to the node failure, mobility and power-down.
- Allowing sensor network middleware to exploit cross-layer information to energy conservation in the communication and surveillance for a long network lifetime when application service quality is met.
- Develop various techniques at the MAC layer to take the availability of cross-layer information to extend node lifetime.
- Soft for real-time communication and Network congestion reduction and control.

The motivation towards the sensor network design is to estimate the underlying physical phenomenon as accurately as possible under the network resource limitation. Thus, the sensor network problem can be formulated as a network optimization problem, in which the objective is to minimize the overall distortion. However, due to the partial observation at each sensor, the overall estimation error at CEO is a coupled and non separable function of all sensors' data rates. In a multihop wireless sensor network, the design goal is to minimize the total distortion by jointly optimizing source coding and power allocation.

C. Issues & Challenges in Multi-Hop Wireless Sensor Networks

There is a growing demand for real-time applications such as voice and image streaming over wireless sensor networks for emergency situations and process control networks require timeliness guarantees across multiple hops while maintaining energy-efficient operation during periods of inactivity. The two fundamental challenges in delivering delay-bounded service in such networks are (a) coordinating transmissions so that all active nodes communicate in a tightly synchronized manner and (b) ensuring all transmissions are collision-free.

We achieve our lifetime and latency goals through tightly-coupled time synchronization across multiple layers of platform design, link layer protocol, and link scheduling algorithms and streaming applications. The basic idea behind our protocol is to provide exclusive and interference-free access to the shared wireless channel and a mechanism to coordinate sleep intervals of all nodes and wake-up only nodes belonging to a routing path from the source to the base station (Sink) by exploiting routing information while other nodes leave maintained as long time as possible in a sleep mode. It is a great challenge of the routing protocol to provide network survivability through redundancy features and proposed routing algorithm is to be designed to cope with the large area of deployment, link or node failures, fire monitoring in similar applications of heterogeneous sensor networks.

I propose a new framework, which has a set of indispensable layers specially tailored to the characteristics of sensor networks. The proposed architecture will be an integrated solution and efficiently address following important issues:

- Constrained Resource (Need Real-time Constraints)
- Link Connectivity & Power Control
- Redundancy
- Security-Sensitive
- Data centric Processing
- High Unpredictability

D. Key Research Problems

Very harsh and dynamic physical environments and extremely limited energy/ computing/ memory communication node resources are major obstacles for satisfying QoS metrics such as reliability timeliness, and system lifetime. The limited communication range of WSN nodes, link asymmetry, and the characteristics of the physical environment lead to a major source of QoS degradation in WSNs. In wireless contention-based medium access control (MAC) protocols, when two nodes that are not visible to each other transmit to a third node that is visible to the former, there will be a collision called hiddennode or blind collision. This problem greatly impacts network throughput, energy-efficiency and message transfer delays, and the problem dramatically increases with the number of nodes.

Several open research problems arise in the development of systematic techniques for cross-layer design of WSN routing protocols for the reference application in context of the proposed framework. I will describe the performance improvement and the consequent risks of a cross-layer approach. I review literature proposing precautionary guidelines and principles for cross- layer design, and suggest some possible research directions. I also present some concerns and precautionary considerations regarding cross-layer design architectures. A cross-layer solution, in fact, generally decreases the level of modularity, which may loose the decoupling between design and development process, making it more difficult to further design improvements and innovations. Moreover, it increases the risk of instability caused by unintended functional dependencies, which are not easily foreseen in a non-layered architecture.

To simplify the problem, following sub-problems are identified in following manner i.e.

To define WSN protocol architecture that can explicitly accommodate cross layer design and optimization issues. The lack of standard architecture prohibits software reusability resulting in waste of time, effort, and money. Also the existing architectures do not support the cross layer design explicitly and therefore, the benefits that one can achieve from cross layer information exchange cannot be achieved. So the task is to define a multihop multi scale WSN architecture which supports cross layer approach and provides plug-and-play features at the same time.

Treating the entire communication protocol stack in a holistic manner can help in finding new means to alleviate the harmful performance restraining consequences of common wireless network problems, such as burst errors due to channel distortions, wireless interference problems, multipath propagation or fading effects.

The problem in multi-hop wireless networks is to estimate their throughout capacity. The problem can be informally stated as given a multi-hop wireless network and a set of source destination pairs, determine the maximum rate at which data can be transmitted between each source destination pair.

Beside the problems of battery power, QoS routing, MAC scheduling, and efficient utilization of network resources, multi-hop wireless networks are more vulnerable to different security risks due to inherent attack prone features such as shared MAC, multi-hop decentralized architecture, wireless medium etc. The attackers can exploit these features to bring serious disorders and routing disruption. Furthermore, multi-hop wireless networks are exposed to multi-layer threats. Hence cross layer security mechanisms are indeed necessary for this adaptive scalable framework.

II. MULTI-HOP CROSS LAYER DESIGN FOR WSN

Wireless sensor networks are formed from small self-powered devices, consisting of one or more sensors, a microprocessor and one or several radio transceivers. The sensors include an analog-to-digital converter, and the microprocessor can be a microcontroller or a low power processor. Wireless sensor network is composed of sensor nodes spread over a geographic area to collect and process data like temperature, humidity, light, seismic related, and images. The number of sensor nodes in WSNs may range from a few tens of nodes to hundreds of thousands nodes depending upon the application. For instance, in container tracking and monitoring application, there are ships which can carry around 14000 containers. Mounting each container with a node would result in a WSN of 14000 sensor nodes. The position of the sensor nodes may not be pre-determined and require sensor nodes to be equipped with self localization protocols or compute it with low power GPS (Global Positioning System).

Wireless sensor network architectures can be classified into flat and hierarchical. Flat WSN architectures are composed of homogenous sensor nodes in terms of resources to collect data and send them to a more resourceful sink node. In this kind of architecture, many to one (M: 1) or many-to-many (M: N) communication is possible. Hierarchical network architectures may include a third tier in the form of an access point. In this discusses mobile sinks to address the issue of energy efficiency. Mobile sinks collect the data from the sensor nodes, buffer that data, and then deliver them to a more powerful device for further processing. Wireless sensor node is comprised of four components including computing, communication, sensing, and power components. Nowadays, it is also composed of a testing module for testing and maintaining of circuit boards.

Cross layer design may be defined as, “the breaking of OSI hierarchical layers in communication networks” or “Protocol design by the violation of reference layered communication architecture is cross-layer design with respect to the particular layered architecture”. Resource constraints in WSN node require energy efficient and energy aware schemes on all layers of the protocol stack to increase the lifetime of the network. The traditional layered networking approach has several drawbacks from WSNs perspective, improvements in performance and energy efficiency are possible if significant amount of information is passed across protocol layers and hence network lifetime can be improved.

Obviously, the approaches summarized and illustrated are limited to information exchange between the layers of one station’s protocol stack. New and maybe unorthodox cross-collaborations between upper and lower layers are introduced, but the measures taken remain limited to the layers of one active station in a communication system. Our suggestion is to consider and integrate intermediate nodes into the idea of cross-layer design and optimization. One can find more opportunities to exploit layer specific information when extending the optimization techniques and algorithms to the layers of intermediate nodes. In many cases, especially in the case of multi-hop transmissions, it would be useful if the transport and routing layers were aware of the conditions and internal parameters of lower layers (MAC and physical layer) of the nodes in their near n-hop neighborhood. Possible application of lower layer knowledge or nearby neighbors are manifold: Nodes could detect signs of congestion, interferences, or irregularities in the transmission pattern early and immediately react to it on routing and transport layer.

Congestion-aware routing protocols could relay their routing decisions on the additional lower layer knowledge. The especially harmful consequences of channel distortions in TCP over multi-hop wireless links could be addressed by exploiting MAC and physical layer knowledge in routing and transport layer of intermediate nodes. In wireless sensor networks with scarce energy resources, the problem to find energy- and latency-optimal channel allocation schemes and routing decisions could be addressed by providing more knowledge about the MAC and physical layer properties to the nodes' routing and transport layers.

The proposed concept of multi-hop cross layer design depicts a source node, four intermediate nodes and a destination node collaborating in a multihop communication system. Nodes are sharing MAC layer information with each other and passing it to the routing layers of their respective n-hop neighbors. The cross-layer information exchange between the MAC layers of the intermediate nodes to the routing layer of node. The same collaboration and parameter exchange however is assumed to take place between the intermediate nodes and their respective n-hop neighbors, too. Our suggestion is to allow information exchange between different layers of different nodes in multi-hop communication schemes.

III. RECENT STUDY

I have surveyed the literature review related to cross-layer designs, protocols, services, and middleware. I will provide background on various protocols used in a layered protocol stack, including node activation, routing and MAC. Node deployments are usually non-uniform: node densities may vary over the region of interest, and not all the nodes may have the same sensing capabilities or compute resources. Redundancy between active nodes wastes precious energy of nodes that may be critical to QoS at a latter point in time. In Ye et al. proposed using local redundancy to lengthen the network lifetime through a protocol called PEAS. The basic idea driving PEAS is that nodes located in densely covered regions can be turned off for long periods of time without significantly degrading the network coverage.

Proactive routing protocols establish routes before a packet is even created and sent, while reactive protocols only do so as needed. Ye et al. proposed GRAB, in which a cost metric field is established. Packet routing simply follows the path with steepest gradient that provides the minimum path cost. Because no consideration may be given to the quality of a link, unreliable paths may be used. GRAB routes packets along several parallel paths to increase robustness. Packets are forwarded in a greedy manner towards the destination. Specifically, each node knows the location of its neighbors, and is able to elect a packet's next-hop as the closest node to the packet destination. In Perkins et al. proposed AODV, a reactive routing protocol that establishes a route to a destination by flooding a route request "RREQ". Upon receiving a RREQ packet, nodes check their route tables for a known path to the destination. Lu et al. proposed DMAC, a MAC protocol whose goal, is to stagger wake-up schedules over paths of a data-gathering tree. DMAC requires local time synchronization. Additionally, broadcast packets from the data sink to the leaf nodes are only supported in specific slots, which may cause increased latency and energy waste when these slots are not used.

Wireless sensor network architectures can be classified into flat and hierarchical. Flat WSN architectures are composed of homogenous sensor nodes in terms of resources to collect data and send them to a more resourceful sink node. Hierarchical network architectures may include a third tier in the form of an access point. Srivastava et al. provide a definition of cross-layer designs and a survey of existing cross-layer models. The authors define cross-layer interactions as back-and forth information flows, merging of adjacent layers, design coupling without a common interface, and vertical calibration across layers. There are several reasons that motivate violating layered architectures: unique hurdles present only in wireless sensor networks, opportunities created by the spatial concurrency of the medium and specific goals of the various applications and end users. Architecture violations render the protocols hard to maintain and complicate in updates. Some violations can have unforeseen effects on the performance of the network. Kawadia offers a concrete comparative look at cross-layer and layered designs. This work makes the case that unintentional cross-layer interactions can have detrimental consequences on system performance.

I compare PEAS to DAPR (Distributed Activation with Predetermined Routes) which is a joint routing and node activation protocol proposed by Perillo et al. The target application is area coverage. The MAC layer is a time-division based scheme where slots are further divided in sections, one of which contains control information that enables neighboring nodes to synchronize appropriately. The routing protocol builds a connected set of active nodes, each sensor making a decision on its own role based on local information exchanged in the control section in time slots of the MAC layer. Lin et al. study the effects of a distributed and imperfect cross-layer rate control scheme, and compare its results to a layered architecture.

Much work has been dedicated to the task of adapting MAC protocols to conditions in the local neighborhood of a node. Van Dam and Langendoen propose T-MAC to improve S-MAC by a novel adaptive active/sleep duty cycle. Pham and Jha introduce MS-MAC, an S-MAC based protocol that adapts S-MAC's listening, sleeping and synchronization cycles to anticipated node movements. Jurdak et al. introduced the idea of adaptive duty cycles in LPL protocols. Because a protocol designer must account for busy regions of the network, a fixed value would have to be set conservatively. Le et al. propose to optimize channel assignment to increase the throughput in multi-channel WSNs using a control theory approach.

Sadler propose a shared platform among all layers of a protocol stack for cross-layer optimizations. Culler et al. propose SNA, a new architecture whose goals are to provide data link abstraction and a modular network layer. XLM takes the reverse approach from the previous architectures by fusing all communication layers into one. Much work has been dedicated to developing and refining important services to improve network protocol performance. Romer proposes a time synchronization scheme that uses clock drift and the exchange of two packets.

K. Romer et al. offer a look at challenges in designing middleware for sensor networks. They identify the need for data-centric communications, adaptive fidelity functions, and QoS knowledge. Wang analyze middleware projects in terms of programming abstractions. Among existing middleware for QoS mechanism, Wang et al. cite MiLAN whose role is to map application requirements to the nodes' sensing capabilities. MiLAN is a proactive middleware that controls the sensors to adapt the network to the application needs as they vary over time, specifying which sensors should send data, route packets, etc. Cornea et al. study middleware optimizations for cross-layer architectures dedicated to interactive mobile video streaming.

IV. Adaptive Approach Incorporate in The Proposed Model

Critical WSN applications require high or even total end-to-end reliability, demanding the use of a reliable transport layer protocol. On the other hand, some of these applications require packet-driven reliability while others only require event-driven reliability. Moving nodes and failing nodes due to battery power depletion are problems that raise a significant number of routing problems, analyze transport and cross layer position-based routing protocols of multihop WSN for industrial control. So demanding the use of efficient routing protocols are simulated, and optimization is performed to enhance energy performance. Many control strategies can compensate for information delay and jitter (delay variations), provided that these can be deterministically bounded or statistically quantified in the design phase. Such assurances are only possible when the link is reliable and collision-free. It is therefore the responsibility of the link layer protocol to provide exclusive and interference-free access to the shared wireless channel and a mechanism to coordinate sleep intervals of all nodes. We achieve our lifetime and latency goals through tightly-coupled time synchronization across multiple layers of platform design, link layer protocol, link scheduling algorithms and streaming applications.

I propose a Cross-Layer Medium Access Control (CL-MAC) protocol using two adjacent layers (MAC and Network) to economize energy for WSN. The basic idea behind our protocol is to wake-up only nodes belonging to a routing path from the source to the base station (Sink) by exploiting routing information while other nodes leave maintained as long time as possible in a sleep mode. It is a great challenge of the hierarchical routing protocol to provide network survivability through redundancy features. A high survivable routing protocol in Self Organizing WSN (HighSSO) and proposed routing algorithm is designed to cope with the large area of deployment, link or node failures and heterogeneous network in forest fire monitoring and similar applications.

Adapting protocols based on current network conditions, protocols can similarly benefit from adaptation based on current application conditions and requirements. In particular, if protocols are proactively informed of the status of active queries in the network, they can adjust their behavior accordingly. With the availability of important network information at all layers in the stack, protocols may tune their internal parameters to improve network performance. A middleware Interpreter that channels information between middleware and protocols to enable the protocols constantly adapt to dynamic application requirements. The Middleware Interpreter proactively notifies protocols of query events, removing the burden of query monitoring and notification from middleware. Many improvements can be observed when using cross-layer information at the MAC layer. The duty cycle of "Low-Power-Listening" (LPL) MAC protocols are investigated with potentially high traffic loads, and several techniques to adapt them (MAC schedule adaptation and path synchronization) to conditions on the network are proposed. Simple information about the packet size or the ratio of packets sent to packets received can be used to improve the lifetime of a sensor node.

We use imaging as inspiration for jointly addressing the problems of scale and localization: combine the scalability of imaging with the generality of sensor networks by interpreting sensor nodes as pixels imaged by one or more sophisticated collector nodes. This in turn enables an architecture in which one or more collectors directly communicate with sensors, bypassing the scaling problems associated with multihop transmission between sensors. Integration of the "views" obtained by multiple collectors enhances coverage, spatial resolution, and estimation of sensor data. Yet there is no significant research done on scalability of algorithms used in wireless sensor networks. I will present a brief survey of recent research on scalability of protocols for wireless ad-hoc networks followed by a scalability analysis of a typical cross-layer scheduling scheme used to improve energy efficiency in wireless sensor networks.

In addition, since sensor nodes frequently switch from sleep mode to active mode, modulation circuits should have fast start-up times. Broadly, they can be divided into pass-band and Ultra-Wideband (UWB) modulation schemes. The main advantages of UWB modulation schemes are their immunity to multipath, very low transmission power and simple transceiver circuit. In order to compare the end-to-end throughput across multiple hops with CSMA and TDMA-based MAX tiling, we simulated a uni-dimensional chain of nodes with a single flow. In order to evaluate our systems throughput and latency performance, we implemented 2-way voice streaming along multiple hops using the ADPCM codec.

Cross layer security mechanisms perform well as compared to traditional approaches. Flooding is one of the most severe security threats in multi-hop wireless networks. We cover several important security challenges, including key establishment, secrecy, authentication, privacy, robustness to denial-of-service attacks, secure routing, and node capture. We also cover several high-level security services required for wireless sensor networks and conclude with future research challenges.

I introduce & propose the adaptive scalable cross layer framework for multi-hop wireless sensor networks as a potential architecture for wireless sensor networks which supports cross layers design, energy management, modularity schemes, new adaptive protocols, self-stabilize, multi-scalable and security management. Lacking of a standardized wireless sensor network specific protocol architecture was the prime motivation to investigate not only this issue so that plug-and-play and the software re-usability of wireless sensor network protocols can be made handy but also many more features mentioned above is in proposed structure.

V. IMPLICATIONS OF THE PROPOSED RESEARCH

Energy performance can be enhanced by designing energy aware hardware and software. Energy aware software approach includes development of energy efficient communication protocols and getting benefits from cross layer interaction among layers. As wireless sensor networks are application dependent, a reference application, container management system would outlined. Protocol architecture which explicitly supports cross layer design is proposed as potential scalable sensor network protocol architecture. Position based routing protocols, for the reference application, which use cross layer information are developed and integrated in this framework for multihop WSN and show that the concept is feasible and can enhance energy efficiency. Simulations show that improved energy efficient solutions are possible with the wireless sensor network protocol architecture. This framework follows routing schemes, topologies, and communication protocols can employ to adapt to enhance performance by using cross layer design concepts. The proposed routing protocols can be used in class of applications where nodes know their absolute or relative positions.

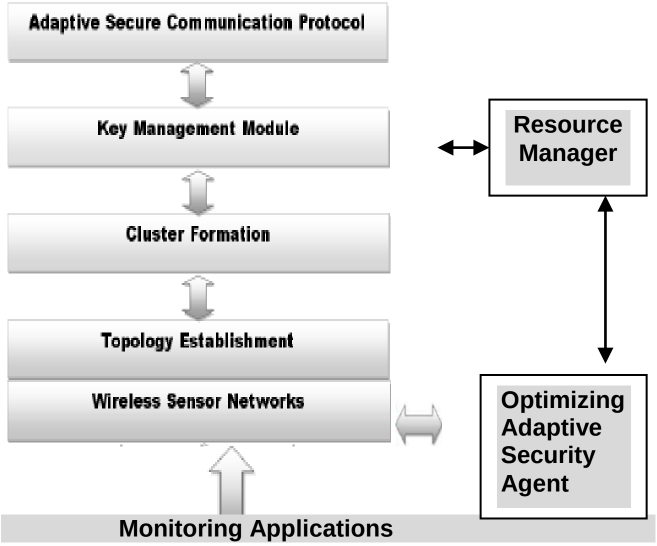

Figure2: Adaptive Optimizing Agent based Framework

A WSN node is split up into different modules, for instance, network layer, application layer, link layer, physical layer, CLAMP, EMP, SMP, ADC, Timers, and CPU etc. Each of these modules is implemented as a C++/Java class. The interfaces are implemented as Remote Procedure Calls (RPCs) which are called functional interfaces. These are used for communication between different modules. All modules are implemented as finite state machines (FSM). Every invocation is managed by the discrete event simulation environment utilizing a future event list. The functional interfaces of a particular layer or plane are invoked by other modules with this framework method invoke (module name, interface name, input parameters, output parameters). When implementing a sensor node on real hardware, different techniques have to be utilized for interfaces and parameters to reduce complexity and overhead. All interfaces should be implementing as regular function calls.

I list the potential open problems that I foresee for multihop WSNs. Then, I stress some reservations about cross-layer design by discussing its pros and cons. we describe possible risks rising when a cross-layer approach is followed, and propose precautionary guidelines and principles. The increased interactions and dependencies across layers turn into an interesting optimization opportunity that may be worth exploiting. Following this intuition, many cross-layer design papers that explore a much richer interaction between parameters across layers have been proposed in the recent past. While, however, as an immediate outcome most of these cross-layer suggestions may yield a performance improvement in terms of throughput. This abstraction decoupling is needed to allow the former to understand the overall system, and the latter to realize a more efficient production. In cross-layer design to improve reliability and optimize performance is advocated, although the design needs to be cautiously developed to provide long-term survivability of cross-layer architectures. In the following, I present some concerns and precautionary considerations, which need to be considered when a cross-layer design architecture is proposed, and suggest some possible research directions.

This adaptive framework allows the physical environment to be measured at high resolutions, and greatly increase the quantity and quality of real-world data and information for applications. Important applications of wireless sensor networks include environmental and habitat monitoring, healthcare monitoring of patients, weather monitoring and forecasting, military and homeland security surveillance, tracking of goods and manufacturing processes, safety monitoring of physical structures and construction sites, smart homes and offices, and many other uses that we do not yet imagine.

VI. CONCLUSION AND FUTURE DIRECTIONS

I outline the main contributions of this proposal and the future work. I suggest ways to adapt sensor networks to conditions in the network and to application requirements by exploiting and organizing cross-layer interactions. An adaptable multiscalable cross-layer design methodology for energy-constrained multihop wireless sensor networks will be an appealing approach as long as cross-layer interactions are thoroughly studied and controlled. Future research will keep the objective of adapting the sensor nodes’ behavior to local conditions in the network and application needs at all time. Consequently, we plan to investigate further how control theory results may be applied to other aspects in the network such as flow fairness and load balancing. WSNs would become invisible part of our every day life. The future research directions of this research would be classified into three categories; real world applications, simulation and modeling, and communication schemes.

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