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Energy efficiency in IEEE 802.15.4/zigbee Sensor Networks: Cross-layer Approach

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ABSTRACT -A major consideration in wireless sensor networks (WSNs) is energy conservation (between 4nodes), although reliability is also very critical. In most cases it is possible to trade-off energy consumption in order to prolong the network lifetime, while satisfying the application requirements. WSNs based on IEEE 802.15.4/Zigbee Suffer from serious unreliability issues, especially when power management is enabled for conserving energy. In this research we propose cross-layer framework for reliable and energy-efficient data (between 4 nodes) collection in WSNs based on the IEEE 802.15.4/Zigbee standards and NS2. The framework involves an energy-aware adaptation module that captures the application's reliability requirements, and autonomously configures the MAC layer based on the network topology and the traffic conditions in order to minimize the power consumption. Our solution can be integrated into WSNs based on IEEE 802.15.4/Zigbee without requiring any modification to the standards. Simulation results show that the cross-layer approach is very energy efficient. The proposed work can be simulated using NS2.

Keywords: Cross-layer framework, reliability, Energy efficiency, Network topology, WSN's, Zigbee.

1. INTRODUCTION:

Wireless sensor networks (WSNs) are being deployed in many real-life applications, such as environmental monitoring, security and surveillance, industrial automation and control [1]. This has been possible due to the advent of: (i) The IEEE 802.15.4 standard [2], which defines the physical and medium access control (MAC) layers of the protocol stack; and (ii) the ZigBee specifications, which cover the network and application layers. A major concern in WSNs is energy conservation, although reliability is also very critical. Indeed, it has been shown that WSNs based on IEEE 802.15.4/ZigBee suffer from serious unreliability issues, especially when power management is enabled for conserving energy. There exist exhaustive amount of research to enable efficient communication in wireless sensor networks (WSNs). Most of the proposed communication protocols improve the energy efficiency to a certain extent by exploiting the collaborative nature of WSNs and its correlation characteristics. However, the main commonality of these protocols is that they follow the traditional layered protocol architecture. Therefore, effective and efficient mechanisms should be provided to achieve reliability with low energy expenditure [3 - 4]. Environmental monitoring applications might tolerate message loss, leading to a trade-off between energy conservation and reliability. For energy efficiency, the WSN protocol stack needs to be tuned according to the actual needs. While these protocols may achieve very high performance in terms of the metrics related to each of these individual layers, they are not jointly optimized to maximize the overall network performance while minimizing the energy expenditure. Considering the scarce energy and processing resources of WSNs, joint optimization and design of networking layers, i.e., cross-layer design stands as the most promising alternative to inefficient traditional layered protocol architectures. The traffic and network conditions in a WSN are often very dynamic, due both to the noisy wireless channel and the failure probability of sensor nodes (e.g., when they run out of battery power). A communication network is composed of nodes, each of which has computing power and can transmit and receive messages over communication links, wireless or cabled [5]. A single network may consist of several interconnected subnets of different topologies. In addition to the information content messages, in some protocols (e.g. FDDI- see below) the nodes transmit special frames to report and identify fault conditions. This can allow network reconfiguration for fault recovery. When a node desires to transmit a message, handshaking protocols with the destination node are used to improve reliability.

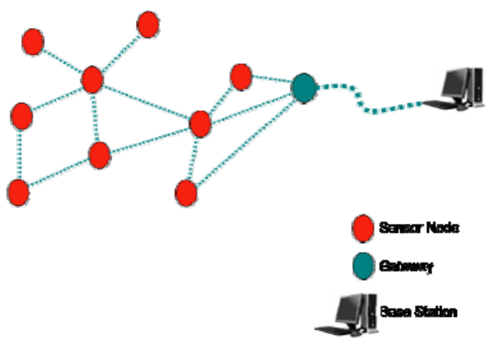

Fig 1: Wireless Sensor Network architecture

Thus, energy-aware and reliable data collection mechanisms should be able to adapt to the actual operating conditions. In addition, they should be flexible enough to support a wide variety of operating scenarios, without any prior or global knowledge on the network topology and the traffic pattern. To this, a cross-layer approach is definitely beneficial, since it can exploit the knowledge provided by the different layers of the protocol stack to minimize the energy expenditure [6]. In this paper we propose a cross-layer approach for reliable and energy-efficient data collection in WSNs based on the IEEE 802.15.4/ZigBee standards [7]. Our approach involves an energy-aware adaptation module that captures the application's reliability requirements and autonomously configures the MAC layer, based on the network topology and current traffic conditions.

2. IEEE 802.15.4 AND ZIGBEE:

ZigBee technology is a low data rate, low power consumption, low cost, wireless networking protocol targeted towards automation and remote control applications. IEEE 802.15.4 committee started working on a low data rate standard a short while later. Then the ZigBee Alliance and the IEEE decided to join forces and ZigBee is the commercial name for this technology. ZigBee is expected to provide low cost and low power connectivity for equipment that needs battery life as long as several months to several years but does not require data transfer rates as high as those enabled by Bluetooth. In addition, ZigBee can be implemented in mesh networks larger than is possible with Bluetooth. ZigBee compliant wireless devices are expected to transmit 10-75 meters, depending on the RF environment and the power output consumption required for a given application, and will operate in the unlicensed RF worldwide (2.4GHz global, 915MHz Americas or 868 MHz Europe). The data rate is 250kbps at 2.4GHz, 40kbps at 915MHz and 20kbps at 868MHz. IEEE and ZigBee Alliance have been working closely to specify the entire protocol stack. IEEE 802.15.4 focuses on the specification of the lower two layers of the protocol (physical and data link layer). On the other hand, ZigBee Alliance aims to provide the upper layers of the protocol stack (From network to the application layer) for interoperable data networking, security services and a range of wireless home and building control solutions, provide interoperability compliance testing, marketing of the standard, advanced engineering for the evolution of the standard. This will assure consumers to buy products from different manufacturers with confidence that the products will work together. IEEE 802.15.4 is now detailing the specification of PHY and MAC by offering building blocks for different types of networking known as"star, mesh, and cluster tree". Network routing schemes are designed to ensure power conservation, and low latency through guaranteed time slots. A unique feature of ZigBee network layer is communication redundancy eliminating"single point of failure" in mesh networks. Key features of PHY include energy and link quality detection, clear channel assessment for improved coexistence with other wireless networks.

As for the channel access, the standard defines two different functions: the beacon enabled and non-beacon enabled modes. The beacon enabled mode provides a power management mechanism based on duty-cycle, and implemented through a super frame structure bounded by beacons, i.e., special synchronization frames generated periodically by the coordinator nodes.

3. CROSS LAYER DESIGN IN WSN:

Many researchers studied the necessity and possibility of taking advantages of cross layer design to improve the power efficiency and system throughput of Wireless sensor network [8-9]. (Safwat et al. 2003) proposed Optimal Cross-Layer Designs for Energy-efficient Wireless Ad hoc and Sensor Networks. They propose Energy-Constrained Path Selection (ECPS) scheme and Energy-Efficient Load Assignment (E2LA). ECPS is a novel energy-efficient scheme for wireless ad hoc and sensor networks. it utilizes cross-layer interactions between the network layer and MAC sublayer. The main objective of the ECPS is to maximize the probability of sending a packet to its destination in at most n transmissions. To achieve this objective, ECPS employs probabilistic dynamic programming (PDP) techniques assigning a unit reward if the favorable event (reaching the destination in n or less transmissions) occurs, and assigns no reward otherwise. Maximizing the expected reward is equivalent to maximizing the probability that the packet reaches the destination in at most n transmissions.

$$\boldsymbol{f_t\ (i) = \{\ 1 \qquad\qquad i = D}$$
$$\boldsymbol{= \{\max_{j} \sum_{k} p_k\ f_{t+k} \quad otherwise}$$

Where D is the destination node and j is the next hop towards the destination D. Any energy-aware route that contains D and the distance between D and the source node is less or equal to n can be used as input to ECPS. The MAC sub-layer provides the network layer with the information pertaining to successfully receiving CTS or an ACK frame, or failure to receive one. Then ECPS chooses the route that will minimize the probability of error. The objective of the E2LA scheme is to distribute the routing load among set Z of Energy aware routes. Packets are allotted to routes based on their willing to save energy. Similar to ECPS, E2LA employs probabilistic dynamic programming techniques and utilize cross-layer interactions between the network and MAC layers.

3.1 Cross layer framework:

As illustrated in Fig. 2, adaptive link layer techniques will be used to adjust the capacity of individual wireless links to support delay-constrained traffic, possibly in multiple service classes; dynamic capacity assignment in the media access (MAC) layer will optimally allocate resources among various traffic flows; a congestion-optimized routing algorithm will provide multiple paths to real-time media streams; finally at the transport and application level, intelligent packet scheduling and error-resilient audio/video coding will be optimized for low-latency delivery over ad-hoc wireless networks. The proposed framework will integrate the above components in a dynamic and iterative fashion.

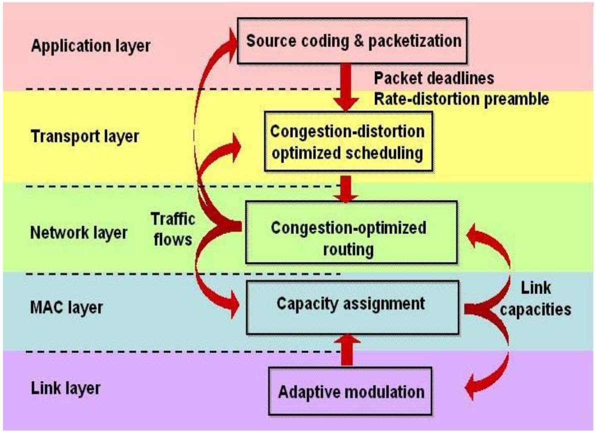

Fig 2: Frame Work architecture.

The proposed framework will integrate the above components in a dynamic and iterative fashion. It allows the exchange of relevant information such as link capacities, traffic flows, packet deadlines and rate-distortion preamble of the source data across the entire protocol stack. Within this framework, we will develop a suite of new techniques for joint optimization, including. As a result, the information coming from one layer can be exploited for tuning the operations of protocols residing in a different (nonadjacent) layer. Specifically, the adaptation module obtains a target level of reliability (in terms of the required delivery ratio) from the application. In order to satisfy the required reliability, the adaptation module continuously monitors the performance of the MAC layer, and provides feedback on the current operating conditions by properly tuning the MAC parameters.

3.2 Cross-layer adaptation module:

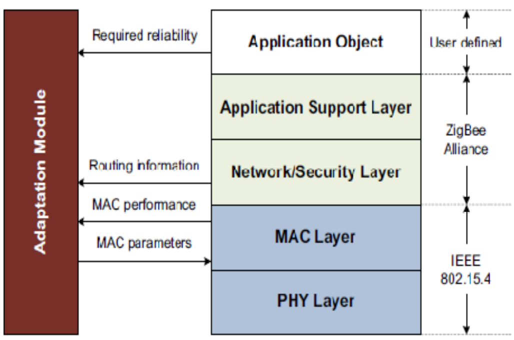

Fig 3: Cross layer Adaption Module.

Our solution to adaptive data collection is cross-layer, and involves an adaptation module which interacts with the different layers of the WSN protocol stack (see Figure 2).Our scheme follows the approach in, where a vertical component is added to the layered architecture to facilitate the sharing of information between different layers of the protocol stack. This avoids duplicating efforts to collect internal state information, and leads to a more efficient system design, as the information collected by the adaptation module can be used for optimizing the protocols' functions. As a result, the information coming from one layer can be exploited for tuning the operations of protocols residing in a different (nonadjacent) layer. Specifically, the adaptation module obtains a target level of reliability (in terms of the required delivery ratio) from the application. In order to satisfy the required reliability, the adaptation module continuously monitors the performance of the MAC layer, and provides feedback on the current operating conditions by properly tuning the MAC parameters. In addition, in multi-hop networks, it exploits the information about the network topology, made available by the routing layer.

4. NETWORK SIMULATOR VERSION 2(NS2):

Network Simulator (Version 2), widely known as NS2, is simply an event driven simulation tool that has proved useful in studying the dynamic nature of communication networks. Simulation of wired as well as wireless network functions and protocols (e.g., routing algorithms, TCP, UDP) can be done using NS2. In general, NS2 provides users with a way of specifying such network protocols and simulating their corresponding behaviours. Due to its flexibility and modular nature, NS2 has gained constant popularity in the networking research community since its birth in 1989. Ever since, several revolutions and revisions have marked the growing maturity of the tool, thanks to substantial contributions from the players in the field. Among these are the University of California and Cornell University who developed the REAL network simulator.

1. The foundation which NS is based on was since 1995 the Defence Advanced Research Projects Agency (DARPA) supported development of NS through the Virtual Inter Network Testbed (VINT) project.
2. Currently the National Science Foundation (NSF) has joined the ride in development. Last but not the least, the group of researchers and developers in the community are constantly working to keep NS2 strong and versatile. Again, the main objective of this book is to provide the readers with insights into the NS2 architecture.

NS2 is a free simulation tool, which can be obtained from. It runs on various platforms including UNIX (or

Linux), Windows, and Mac systems.NS2 source codes are distributed in two forms: The all-in-one suite and the component-wise. With the all-in-one package, users get all the required components along with some optional components. This is basically a recommended choice for the beginners.

5. SIMULATION OUTPUT:

This type of infrastructure can be decentralized (with no central server) or centrally managed (with a central server), both are relatively inexpensive, and very reliable and resilient, as each node needs only transmit as far as the next node. Nodes act as routers to transmit data from nearby nodes to peers that are too far away to reach in a single hop, resulting in a network that can span larger distances.

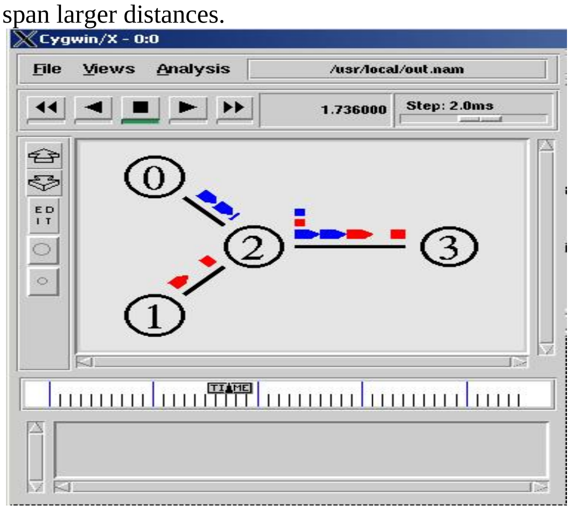

Fig 4: Output for Data transferring at Nodes using NS2 Simulator

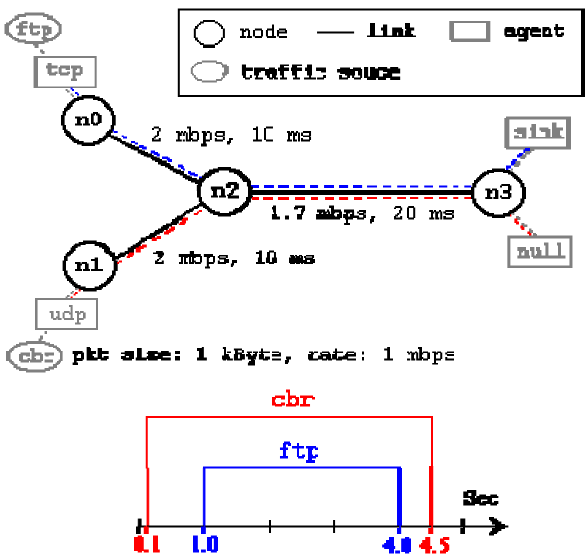

Fig 5: Terminal Output

The same model has been simulated using NS-2 network simulator and the output is shown above in Fig 4.

6. CONCLUSION:

In Future work the mathematical analysis of each wireless sensor node obtained by Markov chain model, and data transfer rate of each node, overall data transfer rate can also be calculated. Energy calculation for wireless sensor network plays major role in large scale sensor network applications. According to the amount of energy is spent on each node while transmitting the data from one node to another node, it is found out the life time of each node ,and also the amount of data transmission occur between two nodes using NS-2 network simulator; the theoretical and simulated results have been presented.

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