Energy Efficient Cross-Layer Network Operation in Mobile Wireless Sensor Networks

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***Abstract*— IEEE 802.15.4 mobile wireless sensor networks (MWSNs) have been investigated in literature. One major finding is that these networks suffer from control packet overhead and delivery ratio degradation. This increases the network's energy consumption. This paper introduces a cross-layer operation model that can improve the energy consumption and system throughput of IEEE 802.15.4 MWSNs. The proposed model integrates four layers in the network operation: 1) application (node location); 2) network (routing); 3) medium access control (MAC); and 4) physical layers. The location of the mobile nodes is embedded in the routing operation after the route discovery process. The location information is then utilized by the MAC layer transmission power control to adjust the transmission range of the node. This is used to minimize the power utilized by the network interface to reduce the energy consumption of the node(s). The model employs a mechanism to minimize the neighbor discovery broadcasts to the active routes only. Reducing control packet broadcasts between the nodes reduces the network's consumed energy. It also decreases the occupation period of the wireless channel. The model operation leads the network to consume less energy while maintaining the network packet delivery ratio. To the best of our knowledge, the presented operational model with its simplicity has never been introduced. Through simulation-based evaluations, the proposed model outperforms the conventional operation of IEEE 802.15.4-based network and the energy efficient and QoS aware multipath routing protocol in terms of energy consumption by roughly 10%, twice less control packet overhead, on-par end-to-end delays and comparative packet delivery ratios.**

***Index Terms*— IEEE 802.15.4 protocol, MAC Layer transmission power Control, Energy Consumption**

I. Introduction

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to *monitor* physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling *control* of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding.

A. APPLICATIONS

Area monitoring: Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors detect enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines.

Environmental/Earth monitoring: The term Environmental Sensor Networks has evolved to cover many applications of WSNs to earth science research. This includes sensing volcanoes, oceans, glaciers, forests, etc. Some of the major areas are listed below.

Air quality monitoring: The degree of pollution in the air has to be measured frequently in order to safeguard people and the environment from any kind of damages due to air pollution. In dangerous surroundings, real time monitoring of harmful gases is an important process because the weather can change rapidly changing key quality parameters.

- **Interior monitoring:** Observing the gas levels at vulnerable areas needs the usage of high-end, sophisticated equipment, capable to satisfy industrial regulations. Wireless internal monitoring solutions facilitate keep tabs on large areas as well as ensure the precise gas concentration degree.

- **Exterior monitoring:** External air quality monitoring needs the use of precise wireless sensors, rain & wind resistant solutions as well as energy reaping methods to assure extensive liberty to machine that will likely have tough access.

Air pollution monitoring: Wireless sensor networks have been deployed in several cities (Stockholm, London and Brisbane) to monitor the concentration of dangerous gases for citizens. These can take advantage of the ad hoc wireless links rather than wired installations, which also make them more mobile for testing readings in different areas. There are various architectures that can be used for such applications as well as different kinds of data analysis and data mining that can be conducted.

Forest fire detection: A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; thanks to Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading.

Landslide detection: A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the occurrence of landslides long before it actually happens.

Water quality monitoring : Water quality monitoring involves analyzing water properties in dams, rivers, lakes & oceans, as well as underground water reserves. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status, and allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval.

Natural disaster prevention: Wireless sensor networks can effectively act to prevent the consequences of natural disasters, like floods. Wireless nodes have successfully been deployed in rivers where changes of the water levels have to be monitored in real time.

B. INDUSTRIAL MONITORING

Machine health monitoring: Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionality. In wired systems, the installation of enough sensors is often limited by the cost of wiring. Previously inaccessible locations, rotating machinery, hazardous or restricted areas, and mobile assets can now be reached with wireless sensors.

Data logging: Main article: Data logging Wireless sensor networks are also used for the collection of data for monitoring of environmental information; this can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants. The statistical information can then be used to show how systems have been working. The advantage of WSNs over conventional loggers is the "live" data feed that is possible.

Industrial sense and control applications: In recent research a vast number of wireless sensor network communication protocols have been developed. While previous research was primarily focused on power awareness, more recent research have begun to consider a wider range of aspects, such as wireless link reliability, real-time capabilities, or quality-of-service. These new aspects are considered as an enabler for future applications in industrial and related wireless sense and control applications, and partially replacing or enhancing conventional wire-based networks by WSN techniques.

Water/Waste water monitoring: Monitoring the quality and level of water includes many activities such as checking the quality of underground or surface water and ensuring a country's water infrastructure for the benefit of both human and animal. The area of water quality monitoring utilizes wireless sensor networks and many manufacturers have launched fresh and advanced applications for the purpose.[14]

- **Observation of water quality:**The whole process includes examining water properties in rivers, dams, oceans, lakes and also in underground water resources. Wireless distributed sensors let users to make a precise map of the water condition as well as making permanent distribution of observing stations in areas of difficult access with no manual data recovery.
- **Water distribution network management:** Manufacturers of water distribution network sensors concentrate on observing the water management structures such as valve and pipes and also making remote access to water meter readings.
- **Preventing natural disaster:** The consequences of natural perils like floods can be effectively prevented with wireless sensor networks. Wireless nodes are distributed in rivers so that changes of the water level can be effectively monitored.

Agriculture: Using wireless sensor networks within the agricultural industry is increasingly common; using a wireless network frees the farmer from the maintenance of wiring in a difficult environment. Gravity feed water systems can be monitored using pressure transmitters to monitor water tank levels, pumps can be controlled using wireless I/O devices and water use can be measured and wirelessly transmitted back to a central control center for billing. Irrigation automation enables more efficient water use and reduces waste

- **Accurate agriculture :**Wireless sensor networks let users to make precise monitoring of the crop at the time of its growth. Hence, farmers can immediately know the state of the item at all its stages which will ease the decision process regarding the time of harvest.
- **Irrigation management:** When real time data is delivered, farmers are able to achieve intelligent irrigation. Data regarding the fields such as temperature level and soil moisture are delivered to farmers through wireless sensor networks. When each plant is joined with a personal irrigation system, farmers can pour the precise amount of

water each plant needs and hence, reduce the cost and improve the quality of the end product. The networks can be employed to manage various actuators in the systems using no wired infrastructure.

- **Greenhouses:** Wireless sensor networks are also used to control the temperature and humidity levels inside commercial greenhouses. When the temperature and humidity drops below specific levels, the greenhouse manager must be notified via e-mail or cell phone text message, or host systems can trigger misting systems, open vents, turn on fans, or control a wide variety of system responses. Recent research in wireless sensor networks in agriculture industry give emphasis on its use in greenhouses, particularly for big exploitations with definite crops. Such microclimatic ambiances need to preserve accurate weather status at all times. Moreover, using multiple distributed sensors will better control the above process, in open surface as well as in the soil.

Passive localization and tracking: The application of WSN to the passive localization and tracking of non-cooperative targets (i.e., people not wearing any tag) has been proposed by exploiting the pervasive and low-cost nature of such technology and the properties of the wireless links which are established in a meshed WSN infrastructure.

Smart home monitoring: Monitoring the activities performed in a smart home is achieved using wireless sensors embedded within everyday objects forming a WSN. State changes to objects based on human manipulation is captured by the wireless sensors network enabling activity-support services.

Characteristics: The main characteristics of a WSN include:

- Power consumption constrains for nodes using batteries or energy harvesting
- Ability to cope with node failures
- Mobility of nodes
- Communication failures
- Heterogeneity of nodes
- Scalability to large scale of deployment
- Ability to withstand harsh environmental conditions
- Ease of use

Sensor nodes can be imagined as small computers, extremely basic in terms of their interfaces and their components. They usually consist of a *processing unit* with limited computational power and limited memory, *sensors* or MEMS (including specific conditioning circuitry), a *communication device* (usually radio transceivers or alternatively optical), and a power source usually in the form of a battery. Other possible inclusions are energy harvesting modules, secondary ASICs, and possibly secondary communication interface (e.g. RS-232 or USB).

The base stations are one or more components of the WSN with much more computational, energy and communication resources. They act as a gateway between sensor nodes and the end user as they typically forward data from the WSN on to a server. Other special components in routing based networks are routers, designed to compute, calculate and distribute the routing tables.

C. PLATFORMS

Standards and specifications: Several standards are currently either ratified or under development by organizations including WAVE2M for wireless sensor networks. There are a number of standardization bodies in the field of WSNs. The IEEE focuses on the physical and MAC layers; the Internet Engineering Task Force works on layers 3 and above. In addition to these, bodies such as the International Society of Automation provide vertical solutions, covering all protocol layers. Finally, there are also several non-standard, proprietary mechanisms and specifications.

Standards are used far less in WSNs than in other computing systems which makes most systems incapable of direct communication between different systems. However predominant standards commonly used in WSN communications include:

- ISA100.11a
- WirelessHART
- IEEE 1451
- ZigBee / 802.15.4
- ZigBee IP
- 6LoWPAN

D. HARDWARE

One major challenge in a WSN is to produce *low cost* and *tiny* sensor nodes. There are an increasing number of small companies producing WSN hardware and the commercial situation can be compared to home computing in the 1970s. Many of the nodes are still in the research and development stage, particularly their software. Also inherent to sensor network adoption is the use of very low power methods for data acquisition.

In many applications, a WSN communicates with over a Local Area Network or Wide Area Network through a gateway. The Gateway acts as a bridge between the WSN and the other network. This enables data to be stored and processed by device with more resources, for example in a remotely located Server_ (computing).

E. SOFTWARE

Energy is the scarcest resource of WSN nodes, and it determines the lifetime of WSNs. WSNs are meant to be deployed in large numbers in various environments, including remote and hostile regions, where ad hoc communications are a key component. For this reason, algorithms and protocols need to address the following issues:

- Lifetime maximization
- Robustness and fault tolerance
- Self-configuration

Lifetime maximization: Energy/Power Consumption of the sensing device should be minimized and sensor nodes should be energy efficient since their limited energy resource determines their lifetime. To conserve power the node should shut off the radio power supply when not in use.

Some of the important topics in WSN (Wireless Sensor Networks) software research are:

- Operating systems
- Security
- Mobility

F. OPERATING SYSTEMS

Operating systems for wireless sensor network nodes are typically less complex than general-purpose operating systems. They more strongly resemble embedded systems, for two reasons. First, wireless sensor networks are typically deployed with a particular application in mind, rather than as a general platform. Second, a need for low costs and low power leads most wireless sensor nodes to have low-power microcontrollers ensuring that mechanisms such as virtual memory are either unnecessary or too expensive to implement.

It is therefore possible to use embedded operating systems such as eCos or uC/OS for sensor networks. However, such operating systems are often designed with real-time properties.

TinyOS is perhaps the first operating system specifically designed for wireless sensor networks. TinyOS is based on an event-driven programming model instead of multithreading. TinyOS programs are composed of *event handlers* and *tasks* with run-to-completion semantics. When an external event occurs, such as an incoming data packet or a sensor reading, TinyOS signals the appropriate event handler to handle the event. Event handlers can post tasks that are scheduled by the TinyOS kernel some time later.

LiteOS is a newly developed OS for wireless sensor networks, which provides UNIX-like abstraction and support for the C programming language.

Contiki is an OS which uses a simpler programming style in C while providing advances such as 6LoWPAN and Protothreads.

RIOT implements a microkernel architecture. It provides multithreading with standard API and allows for development in C/C++. RIOT supports common IoT protocols such as 6LoWPAN, IPv6, RPL, TCP, and UDP.

Online collaborative sensor data management platforms: Online collaborative sensor data management platforms are on-line database services that allow sensor owners to register and connect their devices to feed data into an online database for storage and also allow developers to connect to the database and build their own applications based on that data. Examples include Xively and the Wikisensing platform. Such platforms simplify online collaboration between users over diverse data sets ranging from energy and environment data to that collected from transport services. Other services include allowing developers to embed real-time graphs & widgets in websites; analyse and process historical data pulled from the data feeds; send real-time alerts from any data stream to control scripts, devices and environments.

The architecture of the Wiki sensing system is described in [21] describes the key components of such systems to include APIs and interfaces for online collaborators, a middleware containing the business logic needed for the sensor data management and processing and a storage model suitable for the efficient storage and retrieval of large volumes of data.

Simulation of WSNs; At present, agent-based modeling and simulation is the only paradigm which allows the simulation of complex behavior in the environments of wireless sensors (such as flocking). Agent-based simulation of wireless sensor and ad hoc networks is a relatively new paradigm. Agent-based modelling was originally based on social simulation.

Network simulators like OPNET, NetSim, NS2 and OMNeT can be used to simulate a wireless sensor network.

G. OTHER CONCEPTS

Distributed sensor network; If a centralized architecture is used in a sensor network and the central node fails, then the entire network will collapse, however the reliability of the sensor network can be increased by using a distributed control architecture. Distributed control is used in WSNs for the following reasons:

1. Sensor nodes are prone to failure,
2. For better collection of data
3. To provide nodes with backup in case of failure of the central node

There is also no centralized body to allocate the resources and they have to be self organized.

Data integration and Sensor Web: The data gathered from wireless sensor networks is usually saved in the form of numerical data in a central base station. Additionally, the Open Geospatial Consortium (OGC) is specifying standards for interoperability interfaces and metadata encodings that enable real time integration of heterogeneous sensor webs into the Internet, allowing any individual to monitor or control Wireless Sensor Networks through a Web Browser.

In-network processing: To reduce communication costs some algorithms remove or reduce nodes redundant sensor information and avoid forwarding data that is of no use. As nodes can inspect the data they forward they can measure averages or directionality for example of readings from other nodes. For example, in sensing and monitoring applications, it is generally the case that neighbouring sensor nodes monitoring an environmental feature typically register similar values. This kind of data redundancy due to the spatial correlation between sensor observations inspires the techniques for in-network data aggregation and mining.

1) Features

- ✓ The proposed cross-layer assumes no clustering mechanism has been implemented. This makes the network more flexible in terms of new nodes joining the network.
- ✓ The proposed system improve the energy consumption and system throughput of IEEE 802.15.4

II. RELATED WORKS

We investigate the connectivity for large-scale clustered wireless sensor and ad hoc networks. We study the effect of mobility on the critical transmission range for asymptotic connectivity in k-hop clustered networks and compare to existing results on non clustered stationary networks[1]. By introducing k -hop clustering, any packet from a cluster member can reach a cluster head within k hops, and thus the transmission delay is bounded as Θ(1) for any finite k. We first characterize the critical transmission range for connectivity in mobile k-hop clustered networks where all nodes move under either the random walk mobility model with nontrivial velocity or the i.i.d. mobility model. By the term nontrivial velocity, we mean that the velocity of a node v is ω(r(n)), where r(n) is the transmission range of the node. We then compare with the critical transmission range for stationary k-hop clustered networks. In addition, the critical number of neighbors is studied in a parallel manner for both stationary and mobile networks. We also study the transmission power versus delay tradeoff and the average energy consumption per flow among different types of networks. We show that random walk mobility with nontrivial velocities increases connectivity in k-hop clustered networks, and thus significantly decreases the energy consumption and improves the power-delay tradeoff. The decrease of energy consumption per flow is shown to be Θ([(logn)/(nd)]) in clustered networks. These results provide insights on network design and fundamental guidelines on building a large-scale wireless network. Wireless sensor and actor networks (WSANs), the collaborative operation of sensors enables the distributed sensing of a physical phenomenon [2], while actors collect and process sensor data and perform appropriate actions. WSANs can be thought of as a distributed control system that needs to timely react to sensor information with an effective action. In this paper, coordination and communication problems in WSANs with mobile actors are studied. First, a new location management scheme is proposed to handle the mobility of actors with minimal energy expenditure for the sensors [1], based on a hybrid strategy that includes location updating and location prediction. Actors broadcast location updates limiting their scope based on Voronoi diagrams [2], while sensors predict the movement of actors based on Kalman [2] filtering of previously received updates. The location management scheme enables efficient geographical routing, and based on this, an optimal energy-aware forwarding rule is derived for sensor-actor communication. Consequently, algorithms are proposed that allow controlling the delay of the data-delivery process based on power control, and deal with network congestion by forcing multiple actors to be recipients for traffic generated in the event area. Finally, a model is proposed to optimally assign tasks to actors and control their motion in a coordinated way to accomplish the tasks based on the characteristics of the events. Performance evaluation shows the effectiveness of the proposed solution. Algorithms for navigating a mobile robot through wireless sensor networks are presented [3]. The mobile robot can navigate without the need for a map, compass, or GPS module while interacting with neighboring sensor nodes. Two navigation algorithms are proposed in this paper: the first uses the distance between the mobile robot and each sensor node and the second uses the metric calculated from one-hop neighbors' hop-counts. Periodically measuring the distance or metric, the mobile robot can move toward a point where these values become smaller and finally come to reach the destination. These algorithms do not attempt to localize the mobile robot for navigation, therefore our approach permits cost-effective robot navigation while overcoming the limitations of traditional navigation algorithms. Through a number of experiments and simulations, the performance of the two proposed algorithms is evaluated. We consider the problem of gathering correlated sensor data by a single sink node in a wireless sensor network. We assume that the sensor nodes are energy constrained and design efficient distributed protocols to maximize the network lifetime. Many existing approaches focus on optimizing the routing layer only, but in fact the routing strategy is often coupled with power control in the physical layer and link access in the MAC layer [4]. This paper represents a first effort on network lifetime maximization that jointly considers the three layers. We first assume that link access probabilities are known and consider the joint optimal design of power control and routing. We show that the formulated optimization problem is convex and propose a distributed algorithm, JRPA [4], for the solution. We also discuss the convergence of JRPA. When the optimal link access probabilities are unknown, as in many practical networks, we generalize the problem formulation to encompass all the three layers of routing, power control, and link-layer random access. In this case, the problem cannot be converted into a convex optimization problem, but there exists a duality gap when the Lagrangian dual method is employed. We propose an efficient heuristic algorithm, JRPRA, to solve the general problem, and show through numerical experiments that it can significantly narrow the gap between the computed and optimal solutions. Moreover, even without a priori knowledge of the best link access probabilities predetermined for JRPA, JRPRA achieves extremely competitive performance with JRPA. Beyond the metric of network lifetime, we also discuss how to solve the problem of correlated data gathering under general utility functions. Numerical results are provided to show the convergence of the algorithms and their advantages over existing solutions. Service-oriented wireless sensor networks have recently been proposed to provide an integrated platform [5], where new applications can be rapidly developed through flexible service composition. In wireless sensor networks, sensors are periodically switched into the sleep mode for energy saving. This, however, will cause the unavailability of nodes, which, in turn, incurs disruptions to the service compositions requested by the applications. Thus, it is desirable to maintain enough active sensors in the system to provide each required service at any time in order to achieve dependable service compositions for various applications. In this paper, we study the cross-layer sleep scheduling design, which aims to prolong the network lifetime while satisfying the service availability requirement at the application layer. We formally define the problem, prove that the problem is NP-hard, and develop two approximation algorithms based on the LP relaxation and one efficient reordering heuristic algorithm. The proposed work will enhance the dependability of the service composition in service-oriented wireless sensor networks.

III. PROPOSED SYSTEM

In this project, we propose a cross-layer operation model. At network initialization, the mobile node started to broadcast a neighbor discovery message to initiate neighbor(s) information collection and store it in a neighbors' list (NB-List). After the initialization process, if a node in the network had data of interest to send, attached with this data was the location information of the mobile node. The location information in the node is provided by either a GPS module attached to the node or any other methods where the nodes are able to estimate their individual locations. This node then started sending route request (RREQ) packets to establish a route to the destination node. Hello packets are broadcast packets; therefore, it was possible to utilize the neighbor list from the network layer in the data-link layer.

A. ADVANTAGES OF PROPOSED SYSTEM:

The proposed cross-layer assumes no clustering mechanism has been implemented. This makes the network more flexible in terms of new nodes joining the network.

The proposed system improve the energy consumption and system throughput of IEEE 802.15.4

IV. OBJECTIVES

Input Design is the process of converting a user-oriented description of the input into a computer-based system. This design is important to avoid errors in the data input process and show the correct direction to the management for getting correct information from the computerized system. It is achieved by creating user-friendly screens for the data entry to handle large volume of data. The goal of designing input is to make data entry easier and to be free from errors. The data entry screen is designed in such a way that all the data manipulates can be performed. It also provides record viewing facilities. When the data is entered it will check for its validity. Data can be entered with the help of screens. Appropriate messages are provided as when needed so that the user will not be in maize of instant. Thus the objective of input design is to create an input layout that is easy to follow

V. CONCLUSION

This paper has proposed a simple, intuitive yet highly effective cross-layer network operational model for MWSNs. The network model employs two major mechanisms: the first is controlling the amount of control packets being broadcast in the network to provide a relief for the communication channel between the nodes. The control packet minimization process focuses on the broadcast packets, mainly neighbor, discovery mechanism at the MAC layer and the neighbor discovery packets (hello packets) at the routing layer. The second mechanism is transmission power control that is dependent on the node'(s') location. The transmission power control mechanism is only active when the route is established; therefore, its effect is guaranteed at the data transmission state. Combined together results in energy efficiency, higher throughput and lower end to- end delays than the standard model. To our knowledge, such a combination in the cross-layer operation with four layer cooperation has not been introduced before and is unique.
Future directions for the proposed model is to minimize more control packets especially RREQ packets as they are also broadcast packets. A possible mechanism is to program the mobile so that they know where the sink node is. Therefore, by implementing a directional broadcast flooding, this should minimize the number of control packets being broadcast and improve the channel quality. Another possible improvement over the proposed model is to have heuristic calculated information about the active route life-time. By merging the information of the mobile node(s) movement direction and speed, the active route can be programmed to have a life-time equal to when the first node of this active might leave the connectivity range. Such mechanism can minimize the link error handling messages between the nodes. Applications that can benefit from such implementation can be related to elder care centers or social activity monitoring, e.g., kindergarten monitoring related applications.

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