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Tanja: A framework to Conserve Energy in WSN

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Abstract*— Nowadays, Wireless Sensor Networks raise a growing interest among industries and civil organizations where monitoring and recognition of physical phenomena are a priority. Their possible applications are extremely versatile. WSN represent a significant technology that attracts more and more considerable research attention in recent years. It has emerged as a result of recent advances in low-power digital and analog circuitry, low-power RF design and sensor technology. In this paper we propose a new framework for modeling Wireless Sensor Networks that supports WSN to handle real-time network management by using a hierarchical framework based on general features identified through a careful analysis of existing sensor networks. Our framework is based on the GSM model. In fact, it's an energy optimization approach based on cross-layer for wireless sensor networks, joining optimal design of the physical, medium access control, and routing layer. It can be considered as a special kind of clustering architecture that extends the network life by efficiently using every node's energy and distributes management tasks to support the scalability of the management system in densely deployed sensor networks. However, it is more systematic, more robust and more scalable. In our solution we propose dynamic construction of clustering. The network is partitioned into clusters or cells. A cluster is composed with nodes, where every node can play one of three roles: source or sensing role as a slave, router, or a master as a cluster head and a gateway to the external world. We address the energy-consumption efficiency as a major design challenge in succeeding the vision of self-organized WSN. This approach focuses on the computation of optimal transmission power, routing, and duty-cycle schedule that optimize the WSNs energy-efficiency and by the way, reduces node energy consumption and contributes to extending the lifetime of the entire network.

Keywords*— Energy consumption-efficiency, GSM model, Self-configuration, WSN.

I. INTRODUCTION

WSN [1] consist of a large number of nodes capable of limited computation, wireless communication, and sensing. Each node is composed by a processor, a radio interface, memory, and a battery. The goal of such networks is to monitor environmental conditions and to bridge the gap between the physical and the virtual world. In a WSN, nodes are dispersed over an operational area where the phenomena of interest may appear. They communicate over wireless channels and perform distributed sensing and collaborative data processing. By correlating their output, they can provide functionality that an individual node cannot. Wireless Sensor Network applications are expected to experience an enormous rise in the next few years, as well as the number and variety of sensors deployed in each WSN. The increase of WSN requirements in terms of services and application constraints complicates the efficient modeling of sensor networks and the methodological development of dependable application software [2]. WSN systems are dynamic by nature: sensor node configuration needs to adapt to environment changes, which occurs many times during system execution. [3]. In order to achieve effective coordination between nodes, it is important to address the problems of sensor network organization and the subsequent reorganization and maintenance [4].

In WSN, the communication scenario through sensor nodes leads to some amount of energy wasting. Therefore we need to design suitable techniques and protocols in order to optimize the energy consumption and increase the network lifetime [5]. We address the energy-consumption efficiency as a major design challenge in succeeding the vision of self-organized WSN. Energy is a very critical resource and must be used very sparingly. Therefore, energy efficiency is one of the determining factors for survivability and lifetime of WSN. WSN survivability is one of the critical issues leading the optimization of the energy efficiency to be a major research topic and leaving the other performance metrics like security, QoS and real-time performance as secondary objectives [6].We propose a new architecture that aims reduces node energy consumption and contributes to extending the lifetime of the entire network.

Ta framework is based on the GSM model [7]. It can be considered as a special kind of clustering architecture that extends the network life by efficiently using every node's energy and distributes management tasks to support the scalability of the management system in densely deployed sensor networks. However, it is more systematic, more robust and more scalable. In our solution we propose dynamic construction of clustering. The network is partitioned into clusters or cells. A cluster is composed with nodes, where every node can play one of three roles: source or sensing role as a slave, router, or a master as a cluster head and a gateway to the external world. Distribution of management tasks in sensor nodes is an energy efficient approach and utilizes node resources effectively in a large scale WSN [8]. Therefore, Sensor nodes will take more management responsibilities and decision making in order to achieve a self-managed network.

In order to minimize this energy consumption, several techniques were introduced. Idle listening, high transmission power, and retransmission are the major source of energy waste which result from collision and suboptimal utilization of the available resource. One of techniques that have been introduced in S-MAC protocol is duty cycling mechanism. The goal of this technique is to reduce the energy consumption of idle listening.

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The majority of approaches of controlling transmission power, while keeping network connectivity, aim to decrease both, the unnecessary transmission energy consumption, and the interference among nodes. The power aware routing protocols approach, save significant energy. This approach works by selecting the adequate route which is based on the available energy of nodes or energy demand of transmission paths. The WSN requires the reduction of the energy consumed or the wasted energy such as idle, reception, transmission, etc., in all states. Indeed, all approaches cited above will be applied in the WSN.

The rest of this paper is organized as follow: Section 2 provides a brief review of related work in the literature. The proposed framework is described in Section 3. Section 4 discusses our architecture by highlighting a few significant features. Section 5 is about future works suggested. Finally, section 6 concludes the paper.

II. RELATED WORKS

Self-organization is one of the most significant research topic in the wireless networks. It philosophy involves abstracting the communicating entities into an easily controllable network infrastructure. Clustered or connected dominating set CDS, grid, tree, or mesh based organization are key terms in self-organization.

A self- organized wireless node can be grouped or clustered into an easily manageable network infrastructure [4]. There are several methods to form clustering. Cluster is formed in two stages by nodes. In the first stage, a header is selected among the nodes by election algorithm. In the second stage, the cluster or group is formed due to the interaction between the nodes and the headers [9].

The scheme proposed in [10] is based on cluster formation. The idea of the scheme proposed is partition of the network into different groups or clusters and then a cluster head is appointed for each group. The cluster head perform major tasks and should contains more resources than other cluster members. We should keep in mind that the data can only be transmitted to other clusters through cluster heads. Limitation of accessibility to the nodes under its supervision exists when there is a failure of a cluster head.

The proposed framework, permits sensor nodes to autonomously determine their management role based on the node real time capability like energy. Clustering has been used to address various issues i.e. routing, energy efficiency, management and huge-scale control. In addition, other approaches, concerning cross-layer management, have been introduced for WSN. They can ameliorate the performance of clustering in the Wireless Sensor Networks. Indeed, those approaches can reduce significantly the consumption of energy in WSN communications. They can be nearly divided into three different groups to in terms of interaction or modularity among physical PHY, medium access control MAC, routing, and transport layers.

MAC+PHY: The energy consumption for physical and MAC layer was discussed in [11]. The cross layer solution among the application layer, MAC layer, and the application layer for Wireless Sensor Networks is introduced by [12].

MAC+Routing: In the literature, the receiver-based routing is exploited for MAC and routing cross-layer modularity [13] and [14]. PHY+MAC+Routing: The MAC, PHY layer, and joint routing optimization are introduced in [15], which adopts a variable-length TDMA scheme and MQAM modulation. The optimization of transmission power, transmission rate, and link schedule for TDMA-based WSN was discussed in [16].

III. TANJA ARCHITECTURE

A. *Deployment*

Within the class of wireless ad hoc networks that Tanja framework addresses, transmitter nodes can be installed at specific locations or be placed randomly. They can be thrown out of an airplane and, on landing; they are capable of self-organizing into a network. After the initial deployment the network has to be easily scalable, since new sensor nodes may be added, removed or replaced during the network lifetime, which affects node location, density, and overall topology. Moreover, once deployed, sensors are prone to failures due to the manufacturing defects, environmental conditions or battery depletion.

B. *Low-power approach*

Sensor nodes are typically battery-driven; however, they are too small and too numerous for battery replacement or charging. Moreover, micro sensor networks are often deployed in remote or dangerous environments. Hence, the increase of sensor node lifetime becomes a major design and implementation challenge. The necessary lifetime has a high impact on the required degree of energy efficiency and robustness of the nodes, thereby requiring the minimization of energy expenditure. We concern the energy-consumption efficiency as a major design challenge in succeeding the vision of self-organized WSN and hence we address it in the following sections.

C. *Topology*

The topology of a sensor network has an important impact on several network aspects, including power consumption, battery life and routing mechanisms. In this kind of network, the fundamental idea is that the sensor network is partitioned into a set of clusters or cells (as shown in figure 1). Because of the large number of sensor nodes that are expected to populate a wireless sensor network, direct node-level addressing cannot be considered as a feasible approach, and thus clustering is recognized as an effective means of interacting with dense networks of sensors.

Another motivating factor for the establishment of clustering is that after the deployment of sensor nodes, it is likely that multiple neighboring nodes will observe the same phenomenon and obtain the same codes, thus being reported as identical hosts to the base station. To allow individual nodes to directly report their observations to their base station represents a potential waste of energy caused by the transmissions of duplicated data. In fact, the master node may eliminate duplicate readings and improve the quality of the data by confirming shared observations substantiated by multiple sources. As in the GSM model, the cluster head or the master acts like a Virtual Base Station or BTS; its role consists of managing the nodes that belong to its cluster by refining and compressing the sensed data from the cluster, which reduces the network traffic caused by redundant transmissions, reduces the energy output of its cluster members, and contributes to extending the lifetime of the entire network. Clusters may exchange data with each other to further refine the sensed data across cluster boundaries. This behavior permits high-density sensor deployments to be considered, and treated, as progressively density hierarchies of clusters.

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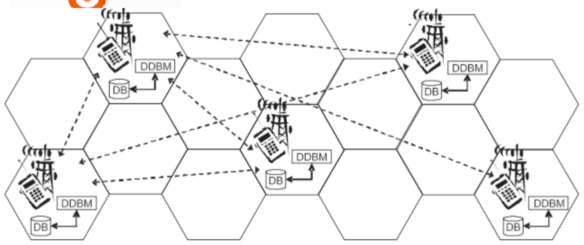

Figure 1 – Mobile / Wireless Ad Hoc Network

Each cluster is composed with nodes, where every node can play one of three roles: source or sensing role when it acts as a slave; router, or master, acting as a cluster head; and a gateway to for interacting with the external world (as shown in figure 2).

Once established, the topology usually does not change when there is no node mobility. However, as nodes perform their assigned tasks, they deplete and eventually exhaust their energy store, causing them to die. The sensor network must be able to detect and recognize failures as well as dynamically adapt itself to changing conditions and maintain the correctness of operations. The topology may be refreshed by the periodic addition of new nodes to the clusters.

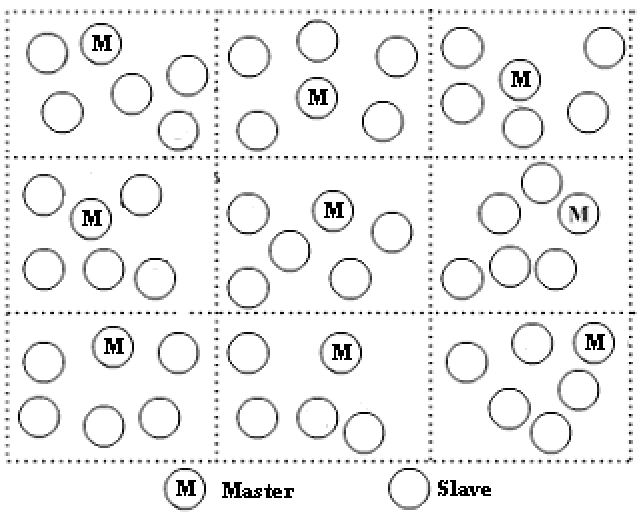

Figure 2 - WSN Cluster architecture

Because of cost and energy constraints, only the master nodes are generally able to transmit data from the sensor network to the "outside world" by means of a longer-range connection. It makes use of a remote Base Station as a gateway to link the external world -such as the Internet or Satellite- to the wireless sensors network (as shown in figure3).

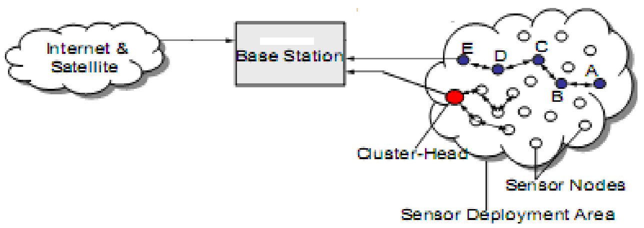

Figure 3 - General WSN architecture

D. Signaling Systems

The signaling system is the nervous system of the network. A great deal of information needs to be passed back and forth between nodes while data transferring as well as in the servicing of specialized features. Here, data refers mainly to the sensed data. Sometimes it also refers to the network infrastructure information concerned by the applications. Four main types of signals handle this passing of information: supervisory signals, alerting signals, connection signals and discovery signals.

1) Discovery signals are used after the deployment of the sensor network in order to setup up and self-organize the whole network. They can be later used for discovering new nodes. Discovery signals convey information consisting of ID, location and energy level of nodes.
2) Supervisory signals handle energy and location status of nodes composing the network. A master is always monitoring its slaves or its cluster members which send back to it their updates, in return, including their node ID and energy level.
3) Connection signals are used in the handover mode. When an acoustic signal strength detected by the master exceeds a predetermined threshold, the active master then broadcasts an information solicitation message, asking sensors in its vicinity to join the cluster and provide their sensing information.
4) Alerting signals are used in the downlink way from the master nodes to nodes belonging to its cell. Those signals perform which nodes will perform sensing and which will go to sleep.

E. Network setup

The enormous number of nodes in sensor networks requires sophisticated solutions for the automatic organization of the network. A manual boot procedure by an administrator is nearly impossible. Therefore, the middleware residing on each node has to autonomously set-up an operating network infrastructure by interacting with its neighboring nodes. For self-organizing networks, the knowledge of the current context (context awareness) is important. During setup phase, infrastructure context (perception of network bandwidth and reliability) and domain context (relation between the network participants) are primarily important. The current system context is necessary for a sensor node to operate correctly. This context can change permanently because of the mobility of nodes, therefore updates mechanisms have to be considered.

F. Self-organization

Upon deployment, the WSN self organizes. Given the large number of nodes and their potential placement in difficult locations, it is essential that the network is able to self-organize; manual configuration is not feasible [17-22]. Moreover, nodes may fail (either from lack of energy of from physical destruction), and new nodes may join the network. Therefore, the network must be able to reconfigure itself periodically. We propose dynamic construction of clustering. Instead of assuming the same role for all the sensors, the sensor network is composed of sensors assuming the role of a cluster head or master upon triggering by certain signal events and sensors whose function is to monitor their environment and provide sensor information to masters upon request. To facilitate scalable operations in sensor networks, sensor nodes should be aggregated to form clusters based on their power levels and proximity. We consider sensor networks where each sensor node is aware of its own location.

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The network can use location services such as [23] and [24] to estimate the locations of the individual nodes, and no GPS receiver is required at each node. Every node sends a discovery message that consist of its node ID, its location and its energy level. The node with the highest life time or energy will be appointed as a cluster master. Sometimes, a secondary parameter is considered in the operation of master selection that is the node's proximity to its neighbors. A master is elected from the sensor nodes belonging to the same cluster, and is responsible for acquiring data from the sensor nodes in its cluster. Masters keep changing in each cluster in order to extend network lifetime. The master broadcasts a supervisory signal to its slaves or its cluster members which in return send their updates including their node ID and energy level. The master maintains a virtual database table, called NODES, whose columns contain information such as sensor location, sensor node ID, and remaining battery power. Upon receiving updates from slaves, the master decides if it keeps its status as a master or must change to the slave role and join the new cluster which belongs to the master that contains the highest energy level. The accomplishment of those tasks leads to the formation of a true WSN.

The master node then decides which nodes will continue performing sensing and which ones will go to sleep. It should enable nodes with more battery, processing, or memory resources to participate more in the network coordination, data aggregation and processing, and data dissemination. A widely employed energy saving technique is to place nodes in sleep mode, corresponding to low power consumption and reduced operational capabilities. Initially, a small number of active nodes participate in routing, being the rest in passive mode. Nodes in passive mode regularly change to test mode and return to active mode when there are not many neighbor nodes and the packet loss is high.

WSN benefits from the fact that clustering attempts to extend network battery lifetime by rotating the role of masters and from protocols that enable sensor nodes to take turns in turning off their transceivers.

G. Transmission Power Control

Power control is necessary to overcome what is known as the near-far problem that is as some slave nodes are closer to cluster head it must reduce its power to avoid causing interference to other slave nodes. The transmission power within the WSN needs to be set the right level dynamically with spatial and temporal change. Temporal and Spatial factors affect the transmission power between Cluster Head and slave nodes. Temporal factors include surrounding environmental changes in general, such as weather conditions, while spatial factors include the surrounding environment, such as terrain and the distance between the transmitter and the receiver. To control the transmission power dynamically, a Received Signal Strength Indicator RSSI was introduced specifying the transmission power level during runtime [25-27].

Every slave node is called to find the minimum transmission power level to communicate with its Cluster Head successfully. The Cluster Head measures the received signal strength in the uplink. The Cluster Head compares the received signal strength to target signal strength. If this one is below the target the cluster head will request the slave node to increase its power and decrease it if above the target.

H. Duty-cycle Scheduling

In order to improve energy consumption, duty cycle mechanisms have been introduced. Sensor MAC (S-MAC) [28] uses new procedures to decrease energy consumption and support self-configuration. S-MAC is based on contention. Each sensor node follows a periodic synchronized listen/sleep schedule. Nodes in the S-MAC exchange their sleeping schedule and before going to sleep nodes broadcast their schedule to their neighbors as a SYNC packet. For S- MAC, energy consumption in idle listening is to be reduced by allowing neighboring nodes of transceiver and receiver to sleep periodically during transmission, by doing so this scheme put nodes into low duty cycle. Figure 4 reflects SMAC listen sleep schedule. Periodically sleeping is good in low traffic cases. If a node can sleep for longer time it consumes less energy.

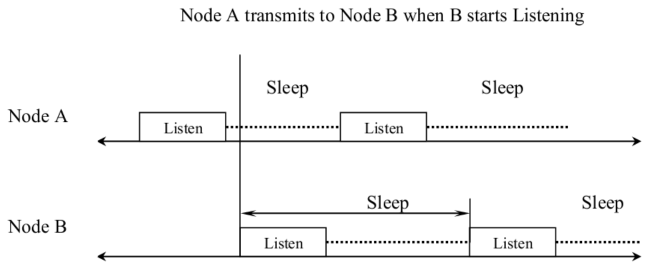

Figure 4 - S-MAC listen/sleep schedule

I. Handover

Based on the GSM technology, we adopt the hand-over protocol on our framework. This method selects the strongest received master node at all times. The decision is based on an average measurement of the received signal. In fact, when the acoustic signal strength detected by the master exceeds a predetermined threshold, the active master then broadcasts an information solicitation packet, asking sensors in its vicinity to join the cluster and providing their sensing information. Hence, the quality of received signal is not degraded because there is no attenuation distance. This method may enable a faster rate of transmission, by taking advantage of the fact that quality of received data from sensors to master node mainly depends on the signal strength (as shown in figure 5).

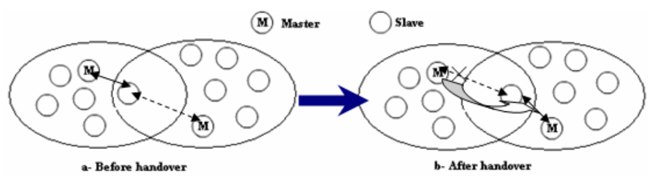

Figure 5 - Node's handover technique

1) Handover Protocol:

   When the acoustic signal detected by the master >
   Threshold_value_neighbors++; //1..i..MAX_CL

2) Algorithm (Master thread):
   (1) broadcast(inform_solicitation);
   (2) while (contacted>0){
       (1) contacted --;
       (2) if (receive(sensor, i))
   nodes++;}
   (3) if (nodes)
       Start receiving sensing information;

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J. Data routing and delivery

The data collected by sensor nodes are pre-processed to obtain partial results and can be stored temporarily before their transmission to the master nodes. These data are then collected by the master node for performing an additional processing to get the final result. Sensors may transfer data in a single-hop from the source node to master node or may instead use multiple hops over several nodes. It is widely accepted that multi-hop data routing provides a greater level of efficiency [29], and contributes to the longevity of the sensor network. This paradigm allows sensor nodes far away from master nodes to transmit data to neighboring sensor nodes, which in turn forward the data towards the intended master node. The forwarding process may cause that multiple sensor nodes on the path between the source node and the collection point get involved. Thus, this paradigm uses a centralized, multi-hop communication model. Regardless of the length of the path, the data eventually reaches the collection point. Coordination among nodes in routing the data to the end point is part of this paradigm.

IV. DISCUSSION

Sensor nodes are usually battery-driven and operate on constrained resource. Achieving energy-efficiency is one of the research challenges to succeed the self-organized vision in large-scale sensor networks. Our architecture addresses this challenge by employing a load balancing strategy so that all nodes remain up and running together for as long as possible. Sensor nodes may fail due to lack of energy, communication problem, physical damage or interference from environment. The network should be able to organize itself. The main idea to propose a model that doesn't consume much energy. It supports sensor nodes to autonomously reconfigure their management roles according to node real-time capability (e.g., energy level). It is based upon the nodes coordination due to which clusters are built automatically and there is no need to exchange too much messages to build the clusters. It considers that management architectures for wireless sensor networks should autonomously adjust and organize themselves according to the network states and node real-time capability without much human intervention.

The GSM architecture is for management purpose only so they can be merged into clusters for routing or any other purpose if needed. The optimal role assignment and reconfiguration model support the network management system to utilize the network nodes in the most efficient manner. Our approach does not rely on specific nodes with extra resources but assign tasks due to their optimal capabilities. Nodes are ranked according to their available energy. The basic idea of this design is to encourage nodes to be more self-manageable and extend the network life time for as long as possible.

V. FUTURE WORKS

We have presented a component framework for developing WSN applications. The reference operational setting, based on a hierarchical architecture of sensor clusters, each one governed by a master, that is elected by cluster nodes autonomously, has been described. We are currently developing a prototype to support the proposed framework. In addition, our future work also includes the implementation of various functions for different significant aspects of network management, such as fault, QoS and mobility management. We are exploring some other experimental middleware trying to find a good balance between performance and easiness.

VI. CONCLUSION

WSN has presented various research challenges and one major challenge is to design an efficient self-organized architecture of wireless sensor network. In this chapter we have presented a new component framework for developing WSN applications. We described a new self-organized architecture based on GSM model for wireless sensor networks. We divide the whole network into multiple cells, where each cell comprises of a group of nodes. In the reference operational setting, based on a self-organized architecture of sensor clusters, each one is governed by a master node that is elected by cluster nodes autonomously. The approach is able to use the physical layer's transmission power as metric to optimize energy consumption, and use S-MAC protocol in duty-cycle.

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