Asian Journal of Scientific Research

ISSN 1992-1454

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Asian Journal of Scientific Research 5 (3): 133-142, 2012
ISSN 1992-1454 / DOI: 10.3923/ajsr.2012.133.142

Maximization of Wireless Sensor Network's Lifetime using Losningen Cross-layer Approach

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ABSTRACT

In energy constrained wireless sensor networks, it was very essential to conserve energy and prolong network's lifetime by using energy efficient protocol. All the sensor nodes in these time-critical wireless sensor networks should meet the lifetime constraint at any time instance else it would cause severe consequences that involve economic losses, or even fatalities. This study aimed to maximize the lifetime of wireless sensor networks using Losningen Cross-layer Approach for single base station scenario. Losningen Cross Layer Approach was merged with data link layer and network layer to provide retransmission, monitoring and tracking facilities for the sensor nodes. It would act as an energy-efficient protocol in ubiquitous network and wireless communication by maximizing network's lifetime. Network Simulator 2 (NS2) was used to verify the proposed protocol for maximization of network's lifetime by analyzing the one among the performance metrics, latency. The simulation results showed that the network's lifetime was increased by conserving the energy of the sensor nodes in Wireless Sensor Network. The proposed approach could be used for battle field surveillance where the uninterrupted data would be highly needed, habitat/wildlife monitoring/tracking and environmental monitoring etc.

Key words: Network lifetime, latency, Losningen cross-layer approach, monitoring, tracking

INTRODUCTION

Recent advances in technology such as wireless communication and embedded systems leads to the development of portable cost efficient, multi-functional sensor nodes. Akyildiz *et al.* (2002) surveyed that sensor nodes can communicate over short distances wirelessly. The sensor nodes epitomizes noteworthy enhancement over existing sensors, as these are capable of accomplishing the processing and communication functions in addition to the sensing function. Maximum energy of the sensor nodes are utilized for the communication purpose. Most of the communication protocols follow the traditional layered protocol (Fig. 1) architectures. Although, this traditional architectures suits well for wired networks it doesn't suit for wireless network. So, for wireless networks, cross-layer designs are attracted due to its properties such as revealing the dependencies, interaction between layers, sharing knowledge about its dynamic status etc. The dependency between many

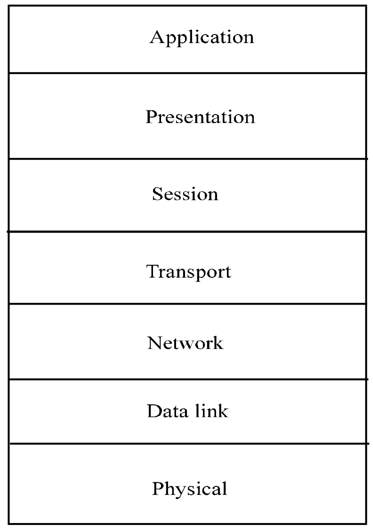

Fig. 1: Layered architecture (layer 1)

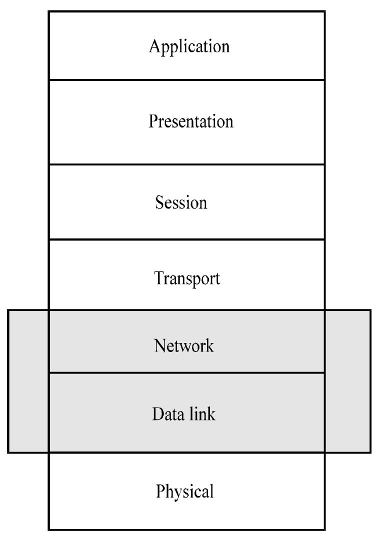

Fig. 2: Losningen cross-layer approach

layers makes it difficult to analyze and redesign the system .Therefore, in this paper, Losningen Cross-layer Approach is proposed which restore the advantage of traditional layered architecture in cross-layer technique by merging data link and network layer (Fig. 2). It is called so as it supports reconfiguration and retransmission in the case of failure of the nodes. The transport of data from a source node to the monitoring station can be carried out on a multi-hop basis using AOMDV routing protocol, where other intermediate sensor nodes act as relay nodes. Particularly AOMDV is used for this approach because the existing routing protocols in ad-hoc networks use the single route between source and sink node. Links in a route may become unavailable by making it invalid due to node mobility, node failures and the dynamic characteristics of the radio channel as explained by Trung *et al.* (2007). Applications of sensor networks (Liu *et al.*, 2010; Wang *et al.*, 2011a) are very broad environmental control of large areas, the protection of various objects, battle field surveillance, monitoring of production processes, controlling complex engineering structures, collecting information on the status of agricultural, monitoring the home and health care (sensornets) (Wei *et al*., 2010) and much more.

Researchers and practitioners have addressed various technical challenges of Wireless Sensor Network (WSN). In this section, various challenges, routing protocols, Medium Access Control (MAC) protocols and cross-layer design of WSN are analyzed in the view of extending the network lifetime in terms of energy efficiency. The main challenge of WSN is the strong dependence of network lifetime on battery lifetime since the nodes are powered by nite energy batteries. Since the efficient usage of battery energy is crucial to enhance the network lifetime, energy conservation technique for increasing network lifetime has been an active area of research.

Rodoplu and Meng (1998) proposed a routing protocol that minimizes the total consumed energy to reach the destination through the minimum energy path but the battery of the nodes present in that path was drained very fast. Then clustering technology was used by the researchers to enhance the lifetime of the network, in this nodes are formed into groups with a cluster head for each group. The nodes send their data to their cluster head and cluster heads in turn communicate to the sink. The cluster head themselves are sensor nodes, the choice of sensor nodes to play cluster head role can be made based on certain probabilistic rules, proximity to other nodes and residual energies in the nodes so as to keep the long network lifetime. Heinzelman *et al*. (2000, 2002) has found that the clusters are formed with respect to received signal strength which save the energy of the individual nodes and the cluster head role is assigned to different nodes based on a probabilistic rule. Instead of forming multiple clusters, in PEGASIS (Power Efficient Gathering in Sensor Information Systems) proposed by Lindsey and Raghavendra (2002) chains are formed in which each node transmit to and receives from a neighbor. One of the nodes in the chain is selected as a leader to transmit to the sink and the chain construction is done in a greedy way. Even though PEGASIS avoids the clustering overheads of LEACH it results in more delay for far-off nodes in the chain from the chain leader. Routing is also performed based on location information of the nodes in the WSN. In Geographic Adaptive Fidelity (GAF) protocol proposed by Xu *et al*. (2001), energy aware location based routing algorithm is used for mobile *ad hoc* networks.

Researchers have proposed several energy efficient MAC protocols to enhance the network lifetime. Time Division Multiple Access (TDMA) based MAC protocol, collision-free MAC protocol is proposed in which the energy consumption of the nodes is less, in turn increase the network lifetime. A survey of MAC is done by Demirkol *et al*. (2006) for WSN based on collision-based and collision-free protocols, shows that the collision-based MAC protocols result in wastage of node energy due to collisions but this can be avoided in collision-free MAC protocol. Also, it would be preferred to avoid continuous listening on the receiver side since energy spent can be saved through interrupted listening that is periodic waking up and listening (Ye *et al*., 2004).

Melodia *et al*. (2006) reviewed the literature on cross-layer protocols, improvements and design methodologies for wireless sensor networks. It also conclude as, cross-layer design methodology is an appealing approach for energy-constrained wireless sensor networks. In cross-layer design of WSN, Fang and McDonald (2004) investigated the effect of broadcast nature of MAC by constructing interference aware routes on routing by merging MAC and network layer. They used AODV routing protocol. Since AODV supports unicast and unipath, it doesn't suits for large scalable wireless network and also for the asymmetric links. To overcome this drawback AOMDV routing protocol is used specifically in the proposed approach. To avoid the mislead in performance evaluation due to the existence of transitional region in low power links, a new strategy for geographic routing with Automatic Repeat Request (ARQ) and without ARQ is proposed by Seada *et al.* (2004). The analysis of power control and congestion control is provided along with trade-off between layered and cross-layer approach by Chiang (2005). But it can be applied the Code Division Multiple Access (CDMA) based wireless multi-hop networks alone which is not feasible for WSNs Cui *et al.* (2005) proposed Joint routing, MAC and link layer optimization by considering variable length TDMA scheme and MQAM modulation to resolve transmission energy and circuit processing energy consumption problem but no communication protocol is proposed for practical implementation, also congestion and flow control issue is not solved. Hou *et al.* (2009) presents a cross-layer Event-Driven Sensor MAC protocol (ED-SMAC) for event-driven WSNs. ED-SMAC defines two network status: Regular status and event status. On regular status, basic SMAC protocols are adopted to reduce the energy waste and guarantee the data transmissions. On event status, a new cross-layer event-based cluster formation algorithm is proposed. Several sensor nodes which have been detected a specific event in the network form a cluster and elect a cluster head. The event information is collected, aggregated and transferred to sink by their elected head. ED-SMAC protocol is well suited for the event driven static distributed WSNs.

Wang *et al.* (2011b) presented an efficient Hybrid Medium Access Control (HMAC) protocol with an embedded cross-layer optimization solution to provide routing-layer coarse-grained end to end Quality-of-service (QoS) support for latency-sensitive traffic flows. HMAC combines channel-allocation schemes from existing contention-based and Time-division Multiple-access (TDMA)- based medium access control (MAC) protocols. HMAC introduces the concept of a short slotted frame structure in which slots are dynamically shared, results in the improvement of energy efficiency. In the case of increase in traffic load, the queuing delays of packets are reduced with the help of short slotted frame structure. It results in reduction of latency and collision between packets, ultimately increase the energy efficiency of the network. Lingyang *et al.* (2009) proposed a cross-layer routing algorithm for WSN by jointly considering channel coding and power allocation, in order to achieve maximum Successful Transmission Rate (STR) subject to a power consumption constraint using DP (Dynamic programming) in order to solve the problem of the traditional routing algorithm, namely, identifying the distance of the next-hop node and to measure the transmission power which is to be allocated to each sensor Wang *et al.* (2007), proposed a new cross layer approach where routing and MAC-PHY layers are jointly considered for energy balancing as well as for energy efficiency. In their approach they used Directional Source-aware Routing Protocol (DSAP) which incorporates power considerations into routing tables.

Abidoye *et al.* (2011), proposed an uniformly distributed cluster heads algorithm to reduce the consumption of energy in WSNs. They partitioned the sensor field into many clusters where each node communicates its information to its corresponding heads with short distance but the latency between the source and the base station is not considered in the algorithm. Kwon and Cho (2008) proposed a power saving scheme in which the length of the beacon interval is adjusted dynamically based on the communication demand. This scheme saves 40% of battery power because of increasing the sleep time if they are not active while compared to IEEE 802.11 power saving scheme. Wang *et al.* (2011a) proposed an energy efficient protocol, CTPEDCA (Cluster-Based and Tree Based Power Efficient Data Collection and Aggregation Protocols for WSNs) which minimize the total energy consumption by using Minimum Spanning Tree (MST) routing strategy. Even though CTPEDCA is better than LEACH, the algorithm of calculating O (Elog V) where V is the set of cluster-heads are very complex. Shanoon-Aiyal *et al.* (2011) analyzed the characteristics of network connectivity by proposing clustering-collective information transmission-routing protocol for non-uniform density WSN. Yang and Zhang (2009) and Guo *et al*. (2011) splitted the network into clusters which is the degradation of energy network as a gradual failure of sensor nodes resulting from the depletion of their limited energy reserves.

SCHEDULABILITY PROBLEM IN WSN

A smart cluster head selection strategy reduces energy consumption which in turn prolongs network life time and its predictability. For this purpose, Cheng *et al*. (2011) used HEF clustering algorithm which chooses the highest energy residue sensor as the cluster head. HEF selects the appropriate cluster head and sends the "setup" message to the cluster head of each cluster which is then broadcast to all the sensor nodes. The sensor nodes then send a "join" message to its cluster head in order to commit to the group. Each cluster head acknowledges this and sends the TDMA schedule to its member's which perform the sensing and processing tasks at each clock cycle. The cluster head receives its member's information at the end of each clock cycle and sends a summation report to the base station using single-hop, in which this process gets delayed in processing while transmitting packets from cluster head to base station. In the proposed approach, this process delay can be reduced by using multi-hop instead of single-hop.

LOSNINGEN CROSS-LAYER APPROACH

Wireless Sensor Networks (WSNs) comprise a great number of nodes with sensing, computing and wireless communication capabilities. Often, WSNs are used in safety-critical or highly-reliable applications. Losningen Cross Layer approach considers network layer and MAC layer jointly which provides retransmission, monitoring and tracking facilities to the network. At the routing layer, the traffic is balanced through the AOMDV routing protocol. The traffic generated by each sensor node are sent through multiple paths instead of using a single path, allows significant energy conservation. On the other hand, at the MAC layer, the retry limits of retransmissions over each wireless link are controlled. Since the retry limit for each link is adjusted efficiently, the energy conservation can be achieved, thus improving the network lifetime. The proposed approach aims to build sensor networks that have the ability to self-configure, to suit varying and possibly unpredictable conditions, constantly monitoring for optimal functioning, be able to find alternative ways to function when it encounters problems and be able to track the environmental changes. In the proposed approach, assume the sensor nodes 1-12 and sink node are distributed in the border of a nation as shown in Fig. 3, gathering the movement of the foreign elements. Node 1, 2 and 7

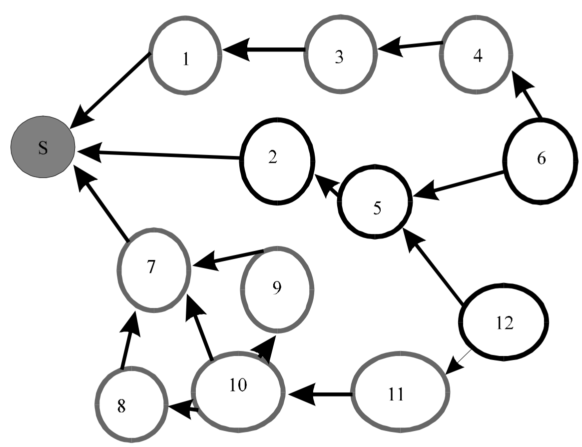

Fig. 3: Multi-hop data transport to sink using single base station scenario

can send the data directly to the sink node while node 6 and 12 use node 5 and 2 as relay node to send their data. Since both node 6 and 12 use node 5 and 2, these nodes will drain its energy earlier, resulting a failure of network which may cause a dangerous effect to the security of the nation. In order to overcome this situation when the node 6 and 12 know about the energy level of node 5 and 2, frequently used for its routing, it can notify the data link layer for link establishment and termination. Then with the help of AOMDV routing of the network layer both the nodes establish the multiple routes to the sink. Fang and McDonald (2004) used AODV for routing to sink. In AODV, when a node needs a route to the sink, by flooding it initiates a route discovery, a route request (RREQ) for the sink in the network and then waits for the route reply (RREP). When the relay nodes receive the first copy of a RREQ packet, it sets up a reverse path to the source node using the previous hop of the RREQ as the next hop on the reverse path. If there is any valid route available to the sink, it unicast RREP back to the source node via the reverse path; otherwise it rebroadcasts the RREQ packet. Duplicate copies of the RREQ are discarded. Sink, on receiving the first copy of a RREQ packet, behaves the same way. As a RREP proceeds to the source node it builds a forward path to the destination at each hop. Since AODV supports unicast and unipath it doesn't suits for large scalable wireless network, also it doesn't support the asymmetric links.

This can be overcome by using AOMDV. Multiple reverse routes to the source node can be formed in AOMDV using the duplicates of the RREQ packet, but it rebroadcasts only one RREQ. Sink node or any node having a path to the sink node may choose to respond to multiple RREQs as it receives through multiple reverse paths which are already formed. Overlapped route mechanism is allowed in AOMDV, beneficial for performance of multipath routing techniques to ensure independence of path failures by providing many forwarding choices at each hop. During routing, next hop links could be too weak to make it strong. RREPs are broadcast instead of unicast which gives opportunity to next hop neighbors on the reverse path to receive the packet successfully and also form the forward path. Another key technique of AOMDV, sequence number-based method is used to avoid looping and also to eliminate decayed routing information. This multipath routing protocol is used to maintain multiple redundant routes to provide load balance and also for fault tolerance. Identifying multiple routes to the sink node reduces the route maintenance overhead when the available routes fail, also it is possible to transmit the data packets without much delay by reducing the load of the individual route which avoid the node failure due to energy drain. Retransmission of data packets can be reduced by reducing the packet loss due to heavy traffic. All these mechanism leads to the energy efficiency of the WSN which increase the network lifetime. Random deployed network located in a 100×100 m area are simulated and the new model is implemented in the heterogeneous form, all nodes initially have the same energy. The adaptive autonomic scalable computing of Losningen cross-layer approach provides self-configuring, self-optimizing and self-protecting, as well as self-healing. The main objectives of Losningen Cross Layer Approach are:

- Providing flexibility through energy-efficient modulation scheme
- Large scale and multi-hop Routing scalability with the localization support
- In the case of node failure, mobility and power-down, network can stabilize by itself
- While transmitting the data if the node fails, the network can reconfigure itself so as to retransmit the information

- It can share the information using cross-layer technique to save energy, thereby extending the node lifetime
- Develop various techniques at the MAC layer to take the availability of cross-layer information to extend node lifetime
- It can provide tracking and monitoring facilities for soft real-time communication network
- Avoids network overloading to prevent data packet losses by multi-hop and traffic control

SIMULATION RESULTS

In AODV, the data is transferred using static channel assignment, taken as default scenario. In the default scenario there is heavy loss of data packets due to overloading of nodes. This drawback is overcome in the proposed scenario. In this study, it is proposed to send the data packets using AOMDV routing protocol in mesh topology specifically. The protocol computes multiple loop-free paths. Retransmission is also guaranteed by using a notion of "advertised multi-hop count". Multicast route establishment is done by using AOMDV; borrows route establishment and maintenance mechanisms from DSR (Dynamic Source Routing) Protocol and sequence numbers, hop-to-hop routing from DSDV (Destination Sequenced Distance Vector) protocols. A duplex link is attached to the nodes to make it a wired network and that enhances the traffic flow between the nodes. A null agent is attached to the sink and then the sources and the sink are connected to one another to generate the flow of traffic between the nodes. The graphs are plotted with latency on y axes and round-trip-time in the x axis as shown in Fig. 4. The simulation results are obtained using network simulator 2 (NS2), one of the network performance metric latency is analyzed. Latency of the proposed model (AOMDV) and default model (AODV) is compared by using the simulation parameters listed in Table 1.

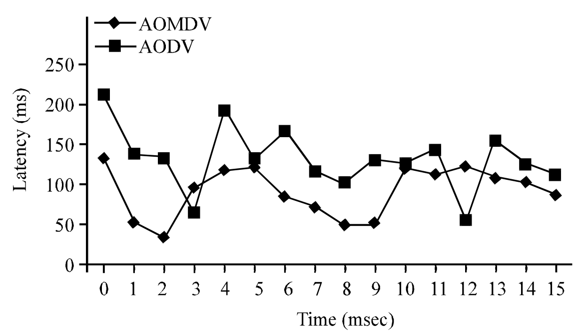

Fig. 4: Latency analysis of proposed model and default model

Table 1: Simulation parameters

Parameters	Value
Number of nodes	75
Network size	100×100 m
Packet size	500 bytes
No. of packets transmitted sec^{-1}	25 packets
Packet transfer interval time	0.04 sec
Traffic	CBR/Poisson/ftp
Channel assignment	Dynamic
Routing protocol	AOMDV

By formula:

$$\text{Latency} = \text{Propagation}+\text{Transmit}+\text{Queue} \tag{1}$$

where, Transmit is the amount of time taken to transmit a unit of data and Queue is the queuing delay. Latency is directly proportional to Transmit and the Queue. In the proposed model since the latency is less, the amount of time taken to transmit a unit of data is also less by the Eq. 1.

Transmit is given by the formula:

$$\text{Transmit} = \frac{\text{Size}}{\text{Throughput}} \tag{2}$$

So, if transmit is reduced; the throughput of the network increased. Also, in the proposed model, the queuing delays are controlled by designing the network to transmit the packets for every 0.04 sec. Finally, the throughput of the network is increased as the latency is reduced in the proposed model.

CONCLUSION AND FUTURE WORK

It can be inferred from the simulation results as the proposed model is able to achieve a remarkable improvement in the end-to-end delay as well as reduce the packet loss probability by controlling the traffic in the network which maximizes the wireless sensor network's lifetime by conserving the energy of the wireless nodes. Finally, the benefits of employing cooperative diversity in enhancing the lifetime of wireless sensor networks are also investigated. By considering a single base station scenario in proposed model using Losningen Cross-layer Approach, the benefit of employing Randomly Deployed Wireless sensor nodes through bounds and simulations are illustrated. Also, simulations have made that show an asymmetric communication with multi-hop extends the lifetime of large wireless sensor networks.

As further extension to this study, optimum selection of cooperating nodes, optimizing system parameters including bandwidth and packet loss and the number of cooperating nodes for network lifetime improvement can be considered. Also Cooperative diversity in the presence of multiple base stations can be also investigated as further extension to this work.

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