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An Insight on Cross-Layer Implementation in Wireless Sensor Networks

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Abstract:

Wireless sensor networks are being used in numerous of application in wide range of environments. They are small in size and often operate on batteries. Any WSN can be assessed on the basis of Communication, sensing and computing capability. In this work we present an overview of layered architecture of wireless sensor network protocol stack and focus on the positives of the cross-layer approach. We also go on to review the literature which have presented the usage of the cross layered approach. Performance evaluation of a WSN is still a big issue where plenty of scheme are available which can optimize the performance .We try to present a few guidelines which may help in the development of the optimization techniques.

Key-Words: - Benchmark, Cross-Layer, Layered Architecture, Performance Evaluation, Wireless Sensor Networks.

I. INTRODUCTION

Wireless sensor networks have found their usage in large number of application in field of electrical engineering, computer science, telecommunications, medicine, biology and other sciences and have been a research targets of scientists from may such fields. They are very versatile owing to their size, cost, intelligence, low power consumption e.t.c. [23]. WSN have been employed in various environment like environment observation, vehicle traffic monitoring, habitat monitoring, industrial automation and health applications.

The basic task performed by the wireless sensor networks are sensing, computing and communications, as in [17].These Sensor nodes are small and cover a huge expanse ,often into areas where they do not get uninterrupted power supplies, so they mostly rely on small batteries with good performance in terms of the days for which these batteries can be used. Therefore one of most important challenge is development of power efficient wireless sensor networks.

Scientists have been stressing on various strategies which can preserve the energy [2]. The best possible way is to optimize routing protocols in layered protocol architecture. This could be accomplished by minimizing energy consumption and/or by maximizing network life time. In [14] these strategies are put in four categories: energy efficient routing, scheduling the node sleeping rate, topology control by tuning node transmission power and reducing the volume of transferred information. Authors in [14] conclude that the hybrid approach work the best and this is what is called as cross-layer approach.

The cross layered approach allows non adjacent layer communication which is not the feature in architecture based on OSI (Open Systems Interconnection) and TCP (Transmission Control Protocol). This provides more space for optimization which improves performances and energy preservation of wireless sensor networks.

For Wireless sensor networks the main energy consumer is the communication part as compared to sensing and computing. Routing and cross-layer optimization try to optimize communication where as optimizing data sensing which reduces computing is also a big challenge [2]. A review through the literature give out the cross-layer approach to be the best solution for energy-efficient communication in wireless sensor networks. However there is no universal systematic methodology for performance evaluation of different optimization methods for wireless sensor networks. There is a need for universal performance evaluation method and standardized metrics so different optimization methods could be compared and evaluated.

The remaining of this paper is organized as follows. Various Layered Architecture has been discussed in Section 2 What is cross-layer approach is discussed in Section 3. Details of cross-layer approach is presented in Section 4. Section 5 discusses the Evaluation of Cross Layer Performance. Section 6 concludes the paper.

II. VARIOUS LAYERED ARCHITECTURES

For understanding the cross layer architecture we try to understand the layered architecture. Traditionally, communication inside wireless sensor network is managed by protocol stack arranged in different layers. Mostly this model has five layers as described in [18] and represents a hybrid between the OSI seven layer model and the four layer TCP/IP model, as shown in Figure 1

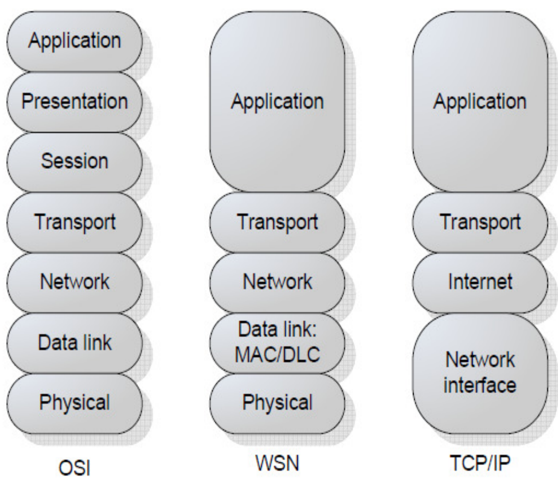

Fig. 1 – Comparison of similar layer models

The protocol stack consists of the physical layer, data link layer, network layer, transport layer and application layer. Responsibility of Physical layer it to convert a bit streams into signal and it is responsible for frequency generation, signal detection, modulation and data encryption. The Data link layer consisting of DLC (Data Link Control) and MAC (Medium Access Control) sublayers is responsible for multiplexing of data streams, data frame detection, medium access and error control. Data routing is taken care by network layer .The transport layer act as a bridge between the application and the network layer employing multiplexing and demultiplexing as and when required .This layer also provides data delivery service between the source and the sink with an error control mechanism and regulates the amount of traffic injected to the network. Application layer act as an interface between the user and the application software[20].

Presented layer architecture of wireless sensor network protocol stack can fluctuate from this universal configuration. References [12] and [13] propose their own adapted architectures which have better performance and lower power consumption.

III. WHAT IS CROSS LAYER APPROACH

All For the architectures presented in section 2 ,all layers are individual and communication is allowed only between adjacent layers. Each layer performs fixed set of responsibility which quite often is in the form of service provided to the layer above it . In the cross-layer approach each layer can share information with any other layer.

As described in [21], following are the reasons to opt for cross-layer approach is based on following:

- Numerous factors determine wireless sensor network system performances. Optimizing individual layer often leads to inefficient solution;
- Individual and isolated optimization results in conflicts in optimization goals;
- Each group of applications requires different functionality. Cross-layer can provide application-specific performance;
- Difference at various platforms are not disclosed by the Cross-layer approach [11];
- Node autonomy and self configuration is promoted by the Cross-layer

approach [11].

In section 4 numerous article have been discussed which have proven the effectiveness of the cross layered approach in terms of energy-efficiency, maximizing network lifetime, maximizing throughput, minimizing delays and others. However with the cross layer approach comes complexity and challenges of big design and interlayer interactions[21].

In [18] and [19] authors classify different kinds of cross-layer approaches from the literature and discuss on the implementation of the cross layered architecture. They stated that cross-layer approach can be performed in four ways:

1. There is a need to create new interfaces at run-time. It can be done into three ways: upward (from lower layer to a higher level), downward (from higher level to a lower layer), back and forth (iterative loop between two layers);
2. Adjacent layers to be merged creating new layer that too without developing new interfaces;
3. Design couplings two or more layers at design time without creating new interfaces;
4. Vertical calibration across layers can be done statically by setting parameters at design time
   or dynamically at runtime.

In [11] cross-layer approaches is classified in two categories. One is information sharing without disturbing the architectural protocol boundaries while the other is design coupling ignoring the layer boundaries and integrating the different layer to optimize network performance metrics. Beside these two categories there is a middle ground solution that preserves layering and enhances it with richer interactions among layers to optimize performance.

IV. DETAILS OF CROSS LAYER APPROACH

In the recent years the Cross-layer approach has found a great leverage ,however there is still a lot of scope of improvement to find a better ,cheaper ,safer and more reliable solution. In the following, state of the art for the cross-layer approach is presented.

Described cross-layered approach in third section applies to information sharing between different layers of one single station's protocol stack. In [10], authors propose a multi-hop communication model in which information can be exchanged between different layers of multiple stations. In experimental environment they implemented this additional feature in WiseMAC protocol. Performance results for case when supplying the routing layers with the knowledge of their two-hop neighborhood, shows that average one-way delay was decreased by 30% without increasing of energy consumption.

If wireless sensor network using implicit knowledge and consisting of a symmetric and asymmetric links between nodes, the message route from source to destination could consist of asymmetric links but this information is hidden from the transport layer and the implicit acknowledgement cannot be sent directly to the source. The obvious solution sit to opt for a cross-layer retransmission protocol family called IMPACT (IMPlicit Acknowledgement Transmission protocol) [4]. With cross-layer acknowledges and dynamic rerouting it results in bigger success rate which enables energy aware communication that has been proved in two experiments (on simulator and on real sensor nodes).

RMC, an energy-aware cross-layer data-gathering protocol for wireless sensor networks is presented in [1]. Integrating routing, MAC and clustering protocols results in reduction of overhead. Compared to cross-layer scheduling scheme presented in [16], RMC increases the network lifetime. However, RMC is location based protocol and implementation in real system poses problems.

In [8], authors presented a cross-layer data reporting scheme that provide an expected information quality at the end system by combining two communication protocols in network and MAC layers: QoS (Quality of Service) aware data reporting tree construction and QoS-aware node scheduling. Simulation results show that their data reporting scheme unaffected by network density with good throughput performance. It is basically a single-hop cluster-based topology,but can easily translated on other topologies also.

The extended DSR (Dynamic Source Routing) algorithm is presented in [7]. The extended DSR uses a cross-layer approach to determine whether the packet loss was the result of congestion or node failure. The DSR increases energy consumption and the extended DSR reduces recomputing by enormous 50%, with further work by being carried in the direction of including TCP layer interactions. be indented.

V. EVALUATION OF CROSS LAYER PERFORMANCE

Wireless sensor network are a part of a big computer system where each node is a small computer in itself consisting of power supply, sensing computing (processing) and communication subsystem. Thus WSN can be seen as collection of small computer systems. As mentioned in [6], various factors of wireless sensor network such as computation at the nodes, network bandwidth, environmental problems and queuing at the sensor in the routing path have influence on performance and power consumption. Each node consumes energy for sensing, data computing, communication and coordination. The major part of energy is consumed in data transmission and computing [2]. Also energy-efficient data acquisition techniques decrease number of communications and reduce data sensing.

Whereas exist numerous different methods for wireless sensor network energy consumption optimization, following question is raised: What optimization approach is the best? In articles where are new optimization methods proposed, authors choose themselves performance evaluation methods. Mostly they compare their proposed optimizations with older one, and then evaluate results of comparison. However, the real contributions of new methods are unknown. As far as we know, there is no universal systematic methodology for performance evaluation of different optimization methods for wireless sensor networks.

In literature, individual performance evaluations are presented. Authors arbitrarily choose benchmark methods and metrics. In [15] authors create a WiSeNBench (Wireless Sensor Network Benchmark) benchmark suite from various sensor network applications for exploring the underlaying architecture. They considered following metrics: codesize, memory accesses, loads in memory accesses, frequent instructions and frequent pairs of instruction. In [3] authors selected benchmarks that represents usual tasks in wireless sensor network applications and perform experimental analysis of wireless sensor nodes current consumption. Performance evaluation of energy efficient ad hoc routing protocols is presented in [5]. For assessment they use energy-related performance metrics such as average delivery ratio, average end-to-end delay, average overhead, average energy consumption and standard deviation of remaining energy among all the nodes. Similar performance metrics as in [5] authors are using in [22] and [9]. In [22] they perform a performance evaluation of IEEE 802.15.4 ad hoc wireless sensor networks. In [9] authors compare performance of the four mobile ad hoc network routing protocols.

For measuring the performance measures of various wireless sensor network optimization methods the universal bench mark suite is used and it should operate across all simulation platforms (e. g. as a framework) and it should be applicable on all types of wireless sensor networks.

The basic optimization goal of the wireless sensor network is to reduce energy consumption. All metrics that have influence on performance and energy consumption of wireless sensor networks should be evaluated. Proposed energy-related performance metrics that should be evaluated in universal benchmark suite are similar as in [5], [22] and [9]:

1. Energy consumption: could have few submetrics as total energy consumption (in some time interval), average energy consumption per received packet or per node;
2. Network lifetime: time until first node failure;
3. Average delivery ratio: ration of packet

sent/packet delivered;

4. Average packet delay: average time taken by the packets to reach its destination;
5. Average overhead: energy consumed for overhearing;
6. Total data aggregation: amount of information sensed/amount of the power consumed by all nodes;
7. Standard deviation of the remaining energy among all nodes.

Additional performance metrics for evaluating wireless sensor network protocols could be:

1. Throughput: average rate of successful packet delivery per amount of time;
2. Average packet journey length;
3. Response time: for event driven sensor networks;
4. Sampling frequency: number of samples taken by each sensor per second.

Some methods work on preplanned structured topology whereas the few other work in an adhoc manner.The universal benchmark suite should consider these two categories separately, however performance metrics should be identical. Performance measurements should be divided according to predefined number of nodes (e. g. 5, 10, 20, …, 1000). These results of performance measurement on different number of nodes could show if optimization methods are affected by scalability and the simulation time should have predefined values (e. g. 10, 20, …, 1000 seconds). Option for various traffic loads would be useful to show method efficiency. Benchmarking must be done under the same conditions for all optimization methods that are included in comparison in order to have valid performance evaluation.

The target of benchmarking is to present wireless sensor network optimization method behavior with numeric values which can be compared and evaluated. From the performance metrics results, optimization methods could be easier classified and therefore their purpose can be specified.

VI. CONCLUSIONS

Wireless sensor networks can be used variety of application in various of environments because they consist of small nodes which are battery operated. Since WSN consume most energy for communication, sensing and computing, different optimization methods are used to improve performance and extend network lifetime. This paper presents state of the art for cross-layer approach in WSN and its utility as compared with the layered protocol architecture. There are numerous optimization method however there should be an universal systematic methodology for performance evaluation. We have tried to address challenges in designing universal benchmark suite and propose some useful guidelines.

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