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Analysis of scalability for routing protocols in wireless sensor networks

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ABSTRACT

The effectiveness of a wireless network relies on the underlying routing protocol. However the characteristics of protocols vary according to the application requirements similar to the quality of service parameters, mobility or scalability. In this paper we analyze the scalability issues of various routing protocols in context to wireless sensor networks (WSN). We present an extensive analysis of the major categories of protocols namely reactive, proactive and hybrid protocols, on various performance metrics that affect sensor networks in particular.

1. Introduction

Wireless sensor network is characterized by autonomous nodes communicating with each other by forming a multi hop radio network and maintaining connectivity in a decentralized manner. Each sensor node has wireless communication capability and some level of intelligence for signal-processing and networking of data [1]. In order to communicate among themselves they harness energy from batteries. The maximum energy consumption occurs while a sensor is communicating with other sensors [2]. Fig. 1 in general, depicts the power consumption profile of a sensor. As energy is the critical resource of a sensor, research in sensor network is primarily centred on energy scavenging. Due to the severe energy constraints of large number of densely deployed sensor nodes, it requires a suite of network protocols to implement various network control and management functions such as synchronization, node localization, and network security. The traditional routing protocols have several shortcomings when applied to WSNs, which are mainly due to the energy-constrained nature of such networks [3]. These reasons insist on the development of power aware routing algorithms which would permit an extended lifetime of the network is of capital importance. The design of these routing protocols is influenced not only by the energy conservation constraints but other factors like scalability. The WSN scalability is the ability of the network to assimilate more number of nodes that might not be foreshadowed during the initial network deployment stage. Scalability act as a major design issue in the wireless sensor network domain because it specifies the system's capability to accommodate additional nodes up to certain threshold without restructuring the entire system [4,5]. Therefore, the routing protocols used for wireless sensor networks should support network scalability where such protocols should continue to do well as the network grows larger or as the workload increases [6,7]. Since there are a variety of routing protocols existing in literature, it is infeasible to evaluate scalability of each protocol. Work related to scalability design issues has been mentioned in [7] which motivate us for further analysis and an extension of the same. Routing protocols can be broadly classified into reactive, proactive and hybrid. Well-known protocols from each family have been considered which can be designated as representatives of that family. The selection of protocols for analysis is based on their advantages and features as mentioned in many literary works. Fig. 2 illustrates the protocols that have been analyzed in our article.

Performance analysis of the routing protocols using ns2 [8] has been done for routing protocols like DSDV, AODV and DSR. It is seen that DSDV performance is poor indicating that it is not suitable for Ad hoc networks. DSR, with aggressive use of cache memory performs better than all the remaining protocols. As proactive or table driven protocols attempt to maintain consistent up-to-date routing information from each node to every other node in the network; each node maintains tables to store routing information, and any changes in network topology need to be reflected by propagating updates throughout the network. Hence the delay in such networks is less. Reactive or on demand protocols are based on

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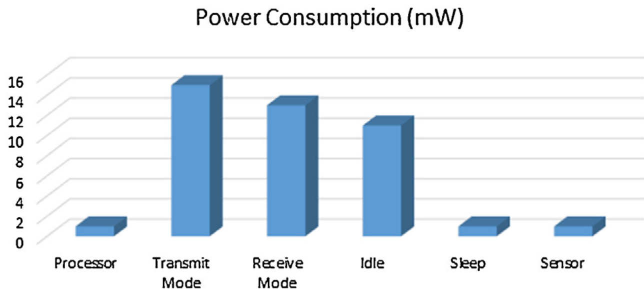

Fig. 1. "Power consumption in sensor node".

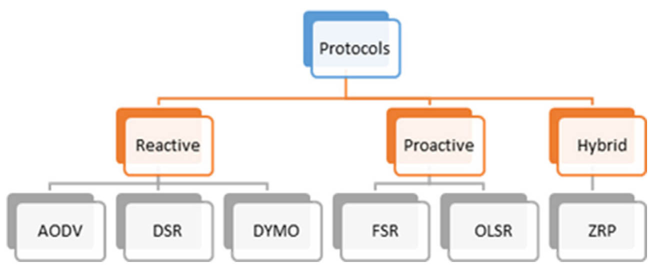

Fig. 2. "Classification of routing protocols in adhoc network".

source initiated on-demand reactive routing. This type of routing creates routes only when a node requires a route to a destination. This initiation of a route discovery process, ends when the route is found [9]. DSDV represents of proactive routing type protocol based on table driven, while AODV and DSR represents of reactive routing protocol type based on demand [10]. DSDV performance is marred by the requirement of maintaining a complete list of routes rather than minimal number of required broadcasts by creating routes on a demand basis. The AODV algorithm enables dynamic, self-starting, multi-hop routing between participating mobile nodes wishing to establish and maintain an ad hoc network [1,4]. The Dynamic Source Routing protocol (DSR) is a reactive and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. It uses source routing which means that the source must know the complete hop sequence to the destination. Each mobile node keeps track of the routes of which it is aware in a route cache. Upon receiving a search request for path, it refers to its route cache to investigate if it contains the required information. However, DSR uses more memory while reducing the route discovery delay in the system [7]. Among these literary works that evaluate the performance of routing protocols in varying domains, none of them mention the suitability of the aforementioned protocols under the scalability perspective. ZRP [11] on the other hand provides some notion of scalability. The absence of hierarchies eliminates definitive points of congestion. It combines both reactive and proactive schemes to find loop free routes to the destination. Also, ZRP limits the scope of the proactive procedure to the node's local neighborhood hence there is a dramatic reduction in cost. Since ad-hoc networks are bandwidth limited and their topology changes often, an Optimized Link-State Protocol (OLSR) has been proposed. While being suitable for small networks, some scalability problems can be seen on larger networks [12]. Our article evaluates the performance of these protocols under different node densities and substantiates their scalability constraints.

2. Performance metric

The special design and character of sensors and their application make WSN's different from traditional networks. These characteristics pose great challenges for architecture and protocol design, performance modelling and implementation [2]. Since WSN are different from traditional networks different metrics are required to capture the overall performance of the wireless network. Few of them, which are used in this work are enumerated as follows.

1. Network Delay: End to end delay at the server is the average time difference between the reception of the packet at the server and the transmission of the packet from source. This metric should be minimized for enhanced performance
2. Network Throughput: Total number of packets received per unit time at the server is defined as throughput at the network. This can be calculated as total packets received at the server divided by average end-to-end delay. This metric must be maximized to improve the performance.
3. Network Jitter: The non-uniform time difference in the arrival of packets at the server, due to time drift, congestion or route updates is known as jitter.
4. Average Carried Load: It is defined as sum of the bits of message generated (per unit time) by the sensor itself, and the bits (per unit time) received from its neighbors. Carried load must be minimum in order to reduce congestion, and energy consumption of the network
5. Average Hop Count: Hop count refers to number of intermediate sensors which a packet needs to traverse in between source sensor and the sink.
6. Energy Consumed: Energy consumed is equal to sum of energy in transmission mode and reception mode. This metric should also be minimum in order to achieve maximum sensor life.

3. Simulation environment

Using the model proposed by Verma et al. [5] the routing protocols were implemented with Qualnet 6.1 simulator [13] over windows platform. The simulations were run on Core2duo 2.8 GHz processor with 2 GB of RAM memory (Table 1).

4. Performance analysis

Fig. 6 displays the average load incurred by the nodes for the given set of protocols. Except Fisheye (FSY), all the protocols incur an invariably small load over the expanse of the network. The increase in load is owing to the link health status check that is performed before routing in Fisheye. It is also observed from Fig. 3 that the end to end delay and jitter statistics is nearly zero for fisheye on larger number of nodes as the packets do not reach the sink at all. The delay for DSR is uniformly low when compared to OLSR and AODV with the increase in node density. Fig. 4 shows the average jitter for protocols that vary according to the increase in node density. It is less for DSR as compared to AODV while for OLSR jitter is less for smaller networks as the routes seldom change. Fisheye

Table 1
Scenario properties.

	Parameters	Values
1.	Nodes	50, 100, 150, 200, 250
2.	Area	1500 × 1500 m
3.	Data rate	2 Mbps
4.	Radio type	802.11b
5.	Packet reception model	PHY802.11b
6.	MAC propagation delay	1 s
7.	Application used	ZigBee
8.	Simulation time	300 s
9.	No. of packets sent	1000
10.	Energy model	MICA motes
11.	Full battery capacity	2400 mAh
12.	Battery model	Residual life estimator
13.	Path loss model	Two ray ground

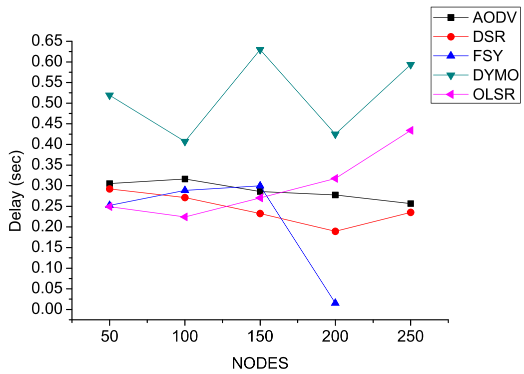

Fig. 3. Average end to end delay of nodes.

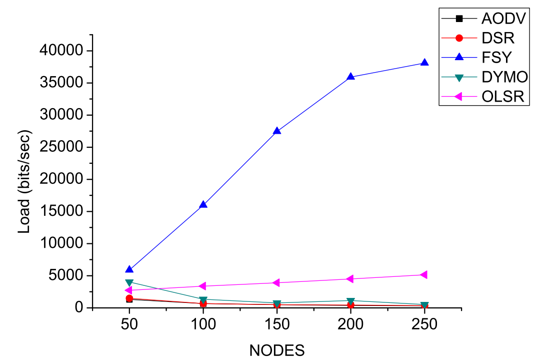

Fig. 6. Average carried load per node.

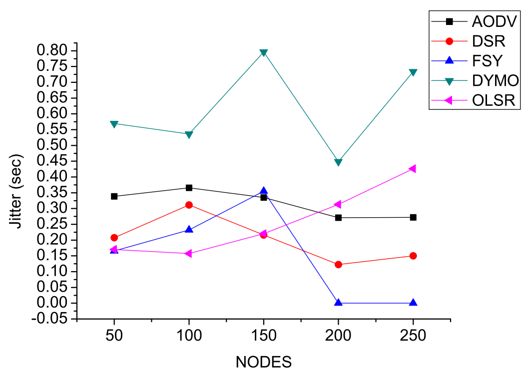

Fig. 4. Average jitter of nodes.

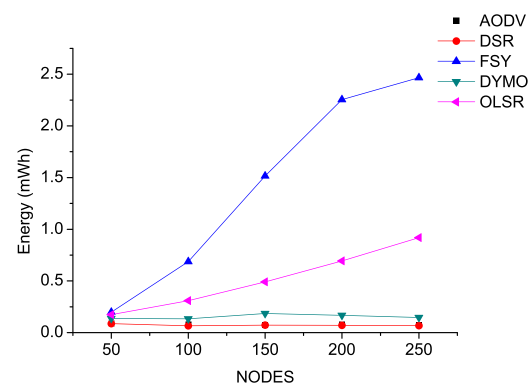

Fig. 7. Average energy consumed in communication (transmission and receiving).

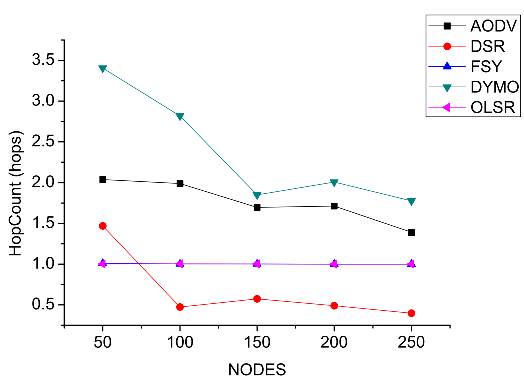

Fig. 5. Total number of hop counts.

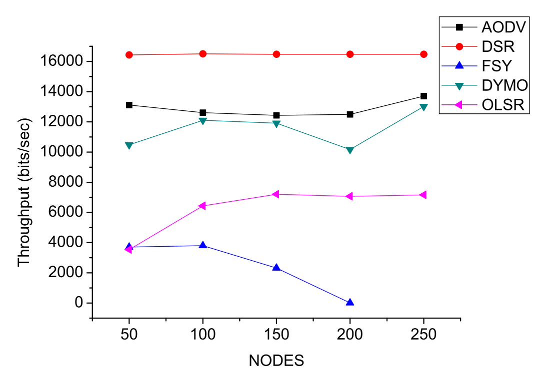

Fig. 8. Total end to end throughput

performs drastically poor and is the least scalable as depicted by all the graphs considered. Hence, we confirm the adoption of reactive routing protocol for large scale Ad hoc networks as the network parameters surpass the proactive protocols. The minimal delay in case of DSR is accounted by a smaller number of hop counts that also is the reason of lesser energy consumption. It indicates that for lesser number of hops, there is lesser contention and congestion in the channel and hence lesser load per node to be carried or forwarded.

Fig. 7 displays the total energy consumption which is the maximum for Fisheye followed by OLSR. We see that the energy consumption of the nodes employing ad hoc protocols is unaffected by the increase in density of the nodes Ad hoc protocols also remain unaffected by the increase in number of nodes with respect to the end to end delay and the end to end throughput of the network shown in Fig. 8. Literatures [14] advocate the performance of DYMO to be better than AODV but we find an erratic behavior attributed probably to its highly dynamic nature in route establishment. The number of hop counts decrease for reactive protocols in larger networks while for reactive and link state based protocols it remains constant as depicted in Fig. 5.

As the results of ZRP protocol could not be merged with the graphs due to discrepancies in representation, we present the results obtained in a separate Table 2. Using a hybrid algorithm like ZRP we find that, the throughput and delay are enormously high. The carried load per node and the number of hop counts is also very high in comparison to the other protocols observed. However, the

Table 2
ZRP statistics.

Nodes	Throughput	Delay	Jitter	Load	Hop count	Energy
50	1767	14.6916	5.1331	1544.8	1.31274	0.11913
100	356	0.48065	0.37626	2247.14	6.40882	0.19122
150	1173	0.48065	0.09439	3310.68	4.27469	0.30262
200	934	4.28503	1.8274	1307.21	2.64711	0.26992
250	572	0.66227	0.33445	1764.52	4.16668	0.34935

Table 3
Rank hierarchy.

Scalability	Metrics adopted					
	Throughput	Delay	Average jitter	Hop counts	Carried load	Energy consumed
Rank 1	DSR	DSR	DSR	DSR	AODV/DSR	AODV/DSR
Rank 2	AODV	AODV	AODV	OLSR/FISHEYE	AODV/DSR	AODV/DSR
Rank 3	DYMO	OLSR	OLSR	OLSR/FISHEYE	DYMO	DYMO
Rank 4	OLSR	DYMO	ZRP	AODV	OLSR	OLSR
Rank 5	FISHEYE	ZRP	DYMO	DYMO	ZRP	ZRP
Rank 6	ZRP	FISHEYE	FISHEYE	ZRP	FISHEYE	FISHEYE

energy consumption is significantly low that justifies its adoption under large networks where energy conservation is the main issue.

Table 3 suggests a basis for evaluating the performance metrics and their suitability to larger networks of the considered protocols on the analytical results presented forth.

5. Conclusion

For highly scalable wireless sensor network applications, which require more number of nodes to be deployed incrementally, we conclude that DSR performs the best under stringent conditions. It is accepted that AODV is adopted as the default protocol for wireless application, on the contrary to the fact that DSR incurs minimum delay, hop counts, average carried load per node and a lesser delay in comparison. Fisheye is suitable for adoption if the network span is less and energy can be replenished while ZRP is suited for applications involving strict energy constraints where delay is not a concern.

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