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A Survey on Concurrent Data Uploading Solutions for Wireless Sensor Networks

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Abstract: ***Wireless sensor networks that operate on batteries have limited network lifetime. There have been extensive recent research efforts on how to design protocols and algorithms to prolong network lifetime. However, due to energy constraint, even under the most efficient protocols and algorithms, the network lifetime may still be unable to meet the mission's requirements. In this paper, background knowledge on data uploading solutions in Wireless Sensor Networks (WSNs) is firstly provided.***

Keywords***:energy constraint,networklifetime,wireless sensor networks(WSNs).***

I. INTRODUCTION

Overview and background on data collection in WSNs

The progression in wireless communications and electronics has facilitated the development of low-cost, low-power and multifunctional sensors. Basically, each sensor node comprises sensing, processing, transmission, power unit, and some optional components (e.g. mobilizer, position system) [3]. A number of these sensors can be networked to fulfill some unattended operations for specific applications, hence forming WSNs. WSNs support a variety of data collection applications, and have profound effects on both military and civil applications, such as environmental monitoring [4][5], tactical military monitoring [6], traffic surveillance [7], video surveillance and physical security [8].

Typically, WSNs contain a large number of sensor nodes. These sensors have the ability to communicate with each other and also can be linked to gateways (sinks or base stations) of WSNs. The measuring and monitoring data packets from multiple sensors are then processed and forwarded to external networks via sinks which act as gateways. This procedure is called data gathering [9].

In such scenarios, the distributed nature and dynamic topology introduce special requirements in the routing schemes. The sensor nodes can make their data route decisions based on its current knowledge of network conditions, application requirements, its computation or energy resources [3]. Each sensor has the ability to collect and route data either to other sensors or to the sinks. The sinks can be fixed stations or mobile nodes that are connected to external infrastructure networks which delivers the data to a network operation control center.

A lot of research has been carried out for the development of WSNs routing strategies in different applications and systems with a variety of requirements and characteristics. The routing protocols can be developed based on the network structure (e.g. flat, hierarchical or location based), the communication model (e.g.query based, negotiation based or coherent based), and the network requirements (e.g. load-balancing based, Quality of Service (QoS) based or energy-efficient based). Routing in WSNs is challenging due to its unique characteristics.

Firstly, the number of sensor nodes in WSNs can be high, thus generate potentially large cumulative traffic. The aggregated traffic volume can be significantly large. Moreover, in WSNs, the nodes close to the sinks are more likely to deplete their battery supplies before the far-away located sensors due to the intersection of multih-hop routes and concentration of data traffic towards the sinks. Hence, routing in WSNs requires fair load balancing of network and equal utilization of gateways.

Secondly, sensors nodes are limited in power, computational capability, and storage capacity. Thus, careful resource management is required in WSNs, especially energy efficient schemes. In multihop scenarios, the sensors act as both data sources and routers, which aggregates their energy consumption. Energy efficient schemes extend the functionality of the network and prolong the network lifetime. Thirdly, WSNs are application-specific, and the design requirements of networks change with different applications. For example, in applications where the time is of vital importance, the most priority of routing design will be data collection latency minimization. Last but not least, the network topology changes due to power failure of sensors or loss of connections of sensors, which requires instant re-organizations. This is to say, the routing algorithm should be adaptable to accommodate the changes of network topologies.

II. BACKGROUND AND RELATED WORK

Due to the recent technological advances in miniaturization, low-power circuit design, and efficient wireless capability, WSNs have emerged as a promising technology with numerous and various military and civil applications, such as environment monitoring [4], disaster management [15], intrusion detection [16], target tracking [17], tactical surveillance [6], and so on [9]. These sensors measure and monitor ambient conditions in the surrounding environment, such as heat, pressure, light, sound, vibration and the presence of objects. The measured and monitored events are then forwarded for data post-analysis toward a more resourceful devices called base stations, gateways or sinks. This procedure is called data collection in WSNs [9].

In order to upload the sensed data and communicate with external networks, the deployed sensor nodes need to target at one or more sinks, which are responsible for data collection within a certain area. The communication can take place through multi-hop paths if the sink can not be reached directly. Various methods have been proposed to address the gateway selection/data collection routing problem. In this section we present a literature review of the studies. Generally, the data collection procedure can be broken down into three steps:

Measurement, decision and execution.

(i). In the measurement phase, the goal is to collect network information. Based on various user policy and application QoS requirements, parameters (e.g. End-to-End (E2E) delay, throughput, and traffic load) in objective metrics need to be measured in this phase. The accuracy of the metrics and decisions depends on the measurement accuracy of these parameters.

(ii). In the decision phase, the task is to design objective metrics in applicable levels, including packet level, flow level and user level. The routing decisions can be made for individual data packet, or can be made on user basis.

(iii). The last step aims to determine the algorithm execution timings. The execution can be periodic or event based.

3 Routing challenges and design issues

Efficient data collection solution is a challenging task due to the unique characteristics of WSNs [48][49]. Firstly, the sensors are constrained in energy supply, processing and storage capacities. Thus, resource management needs to be considered jointly with routing algorithms. Additionally, substantial power demand is incurred for long distance transmissions. Since the transceiver is the major source of energy consumption for the nodes, the optimization of the hop length for routing can significantly reduce the network energy consumption. Secondly, the topology maintenance cost is high in WSNs. The relatively large number of sensor nodes require high maintenance overheads which consume high network resources.

Moreover, sensor nodes are deployed in an ad-hoc manner, which needs self-organization. In the operation where the sensor networks are unattended, the ad-hoc deployment is especially required for sensors to form connections. The self-organizing and ad hoc deployment of WSNs make the data collection paths spontaneous and random, which may generate significant redundant data and also cause severe unbalanced traffic through the network.

Thirdly, WSNs are typically deployed for specific applications that could require distinguished QoS requirements. The satisfaction of various QoS requirements can cause behaviour conflicts of the routing algorithms. These challenging factors must be overcome to ensure that efficient communication can be achieved in WSNs.

Some major design issues that affect routing process in WSNs are summarized as follows:

(i). Energy consumption: Each node plays a dual-role as both data sender and data router that drain energy quickly. Sensors can easily use up their energy supply without proper energy management scheme. The loss of connections for some nodes due to power failure can cause significant topological changes and might need reorganization of the entire network. Thus, accurate energy consumption estimation and energy management schemes are necessary.

(ii). Network topology: There can be a huge number of sensors deployed in a wide area. In this case, the sensors are first expected to be highly connected, with no nodes being isolated. Then the routing scheme should be scalable enough to deal with all the sensors and respond to any event in the network

(iii). QoS: Different QoS requirements are desired for different applications. For example, time-constrained applications require bounded latency for data delivery to ensure the data delivered within a certain period of time. However, in some cases, the conservation of energy may be considered more important than the delivery quality, as it is directly related to the network lifetime. Thus, different applications require to balance the trade-off between delivery quality and energy dissipation, which essentially has the effects on network lifetime.

2.2 Routing algorithms for data collection in WSNs

WSNs are usually deployed for specific application scenarios. Their designs highly depend on the requirements of different applications in terms of reliability, delay and 2.2.2 Load balancing based routing solutions in multiplesink scenarios

In data collection scenarios, sinks are responsible for aggregating all the data packets generated within WSNs. Thus, in order to route the packets for far-away sensors, the sensors near the sinks are more likely to be energy-drained quickly. Because of the low-cost tiny devices, the operation of the network is highly energy sensitive. The lifetime of the network largely depends on the energy of the sensor nodes, which relays all messages to the sinks on the last hop. The nodes close to the throughput. In the following, the state-of-art routing designs for WSNs are surveyed.

2.2.1 Taxonomy of routing algorithms for data collection in WSNs

The studies can be categorized according to different criteria as shown in Fig. 2.1. A widely-used category criterion is the way that the gateways are discovered and the gateways/paths information collected. For this purpose, proactive, reactive and hybrid mechanisms all have their own advantages. Optimized Link State Routing (OLSR) [51] is a basic proactive link state routing protocol. It uses "HELLO" and "Topology Control (TC)" messages to discover and disseminate

Figure 2.1: Category illustration of multi-hop routing solutions.

gateways are more likely to deplete their battery supplies. The node death would lead to disruptions in the topology and reduction of sensing cover-age. Besides, gateways/sinks may become isolated wherein sensor data would no longer be obtained. Moreover, the self-organizing ad-hoc behaviours of a large number of sensor nodes may cause severe unbalanced tra_c through the net- work. Therefore, routing protocols should incorporate load-balancing in order to achieve balanced energy consumption throughout the network.

Table 2.1: Load balancing solutions for gateway selection

Refs	Information discovery	Selection criteria	Decision making
[22]	Reactive	Number of register nodes; Expected interference; Hop distance	Centralised
[28]	Hybrid	Path available period; Path available capacity; Path latency	Distributed
[66]	Proactive	Hop distance; Number of register nodes; Node density	Gateway centralised
[25]	Proactive	Expected throughput; MAC link interference	Distributed
[21]	Proactive	Gateway traffic load; Hop distance threshold	Gateway centralised
[67]	Proactive	Gateway residual capacity; Hop distance	Centralised
[68]	Reactive	Gateway traffic load; Hop distance	Distributed
[27]	Proactive	Contention level; Congestion level; Hop distance	Gateway centralised
[29]	Proactive	Hop distance; Traffic volume	Gateway centralised
[69]	Proactive	Traffic volume	Distributed
[70]	Proactive	Residual capacity	Distributed
[71]	Proactive	Average queue length	Gateway centralised
[72]	Proactive	Number of registered nodes	Gateway centralised
[73]	Proactive	Gateway load; Route interference; Expected link quality	Centralised
[74]	Proactive	Expected link quality; Interference ratio; Gateway load	Distributed

2.2.2.1 In-network load balancing

The studies in this category propose various path quality metrics, aiming to obtain an even and fair distribution of the collected data tra_c among the set of available paths. A balanced tra_c load within the network may create congested links, which causes packet drops, excessive packet retransmissions, and hence low network throughput. For instance, Mhatre et al. [25] propose a load balancing algorithm based on the Expected Throughput (ETP) [26] routing metric which takes into account the capacity reduction of a link due to its interaction with other links within its contention domain. Network information is achieved by neighbour message exchange, which reduces control message overhead. Even though the ow characters on the paths are considered, the study focuses on minimizing expected delay over the entire network and can not provide load-balancing result.

In [27], the contention level, congestion level, and hop distance are combined as the selection metric to avoid areas with high data tra_c or channel contention.

Similarly, the algorithm in [28] combines multiple network performance metrics, including path availability period, residual link capacity, and latency.

2.3 Routing protocols with mobile sinks for WSN data collection

In WSNs with static sinks, the nodes close to the sinks are more likely to deplete their battery supplies before the far-away located nodes due to the intersection of multi-hop routes and concentration of data tra_c towards the sinks [31]. To achieve uniformity of energy consumption, load balancing algorithms are incorporated in routing solutions as surveyed in Sec. 2.2.2. Recently, The usage of Mobile Sinks (MSs) is proposed and explored as an alternative solution to this problem [10{13, 31, 32]. In some papers, mobile sinks are also referred as Mobile Agents (MAs) [13], Mobile Collectors (MCs), or Mobile Relays (MRs) [11].

Conclusion and Future Work

6.1 Conclusion

In this paper, we have researched the issues and made three contributions to the literature of ancient data collection in WSNs. The contributions are summarized in the following: Firstly, a united solution for gateway and in-network tra_c load balancing in multihop data collection scenarios - RALB is developed. This work aims to deal with the potential trade-o_ between in-network tra_c load balancing and gateway utilization equalization. RALB combines multiple path metrics (path residual bandwidth, end-to-end delay and path reliability) and gateway conditions

(gateway utilization) in a united path quality metric. It probabilistically choose alternative path and adaptively modules its path switch probability by means of independent decisions made by network sensor nodes. The simulation results show that RALB reduces the deference in the utilizations of multiple available network gateways and improves network performance by avoiding less quailed data paths, which provides less end-to-end delay in packet delivery and comparable packet delivery ratio to AOMDV. This shows its well-balanced trade-o between in-network load balancing and gateway tra_c load balancing. Moreover, RALB is also shown to maintain a high level of packet delivery ratio and reduce the control overhead which shows its well-balanced trade-o_ between load balancing and network performance. The well balanced performance demonstrates that RALB can be e_ectively adapted to practical remote environment monitoring scenarios, where the sensors are constrained with resources and the gateways conditions are critical.

Secondly, the delay aware energy e_cient data collection with mobile sink and VMIMO techniques problem is formulated into an integer linear program. The objective is to minimize the overall network energy consumption with a constraint of data collection time requirement. A WR algorithm is proposed to approximate the optimal solution. To explore the trade-o_ between overall network energy consumption and data collection latency, WR combines energy consumption, VMIMO utilization and sink moving tour length into a uni_ed weighted metric. Extensive simulation results demonstrate the e_ectiveness of the proposed algorithm: WR largely reduces the overall network energy consumption with bounded sink moving tour length. It proves that the proposed algorithm can be well applicable to the networks with constraint energy and tolerable delay. Moreover, the results show that WR can be adaptively applied for di_erent QoS-requirement applications by adjusting the weighting factors and its emphasis

aggressiveness.

6.2 Future work

In this section, the future research directions are discussed in following two aspects to further improve the proposed algorithms in the area of e_cient data collection with VMIMO and mobile sink techniques.

Firstly, the proposed algorithms can be improved and extended for practical scenarios. The cost of sharing control information for VMIMO transmission, interference of data transmission among sensors and channel state information (CSI) are all not considered in our proposed algorithms, which is not practical in realistic networks. The improved algorithms could be developed in network simulator considering the physical interference model and imperfect knowledge of CSI. It is worth investigating the e_ects of these practical conditions for data collection in WSNs. Furthermore, the organization and formulation of compatible sensors are desired to be improved in a distributed manner, to avoid the large centralization control message overhead in large-scale networks.

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