A REVIEW ON PHYSICAL LAYER CONNECTIVITY OF INTERNET OF THINGS

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Abstract

Internet of things (IoT) are low-cost, low-powered processing nodes embedded with electronics to facilitates the exchange of data between them and with a processing centre. IoT devices are often deployed as sensors to form a network together with a sink node. They are normally used for monitoring applications, tracking, and disaster detection. Most of these sensors are battery powered and the batteries are energy-limited. To ensure continuous task performance by the sensors, several algorithms have been developed to maximise the battery lifetime. However, due to the high operational cost incurred as a result of the replacement of exhausted batteries coupled with difficulties in replacing batteries of sensors deployed in relatively inaccessible areas, rechargeable-battery IoT network is seen as a way forward. Theexisting solutions for energy-limited sensor networksare insufficient or inappropriate for the recently proposed network paradigm:the rechargeable-battery sensor network. Moreover, ensuring the ubiquitous connectivity of the sensing region has become more challenging than in the battery-limited powered IoT network. This paper provides a comprehensive state-of-the-art review on IoT wireless sensor network connectivity on the physical layer and presents recommendations on directions for further research.

Keywords: Internet of things, wireless sensor networks, sensor nodes, wireless chargers.

Introduction

Internet of things (IoT) finds applications in almost all aspects of life because they provide a platform for integrating the physical world with the cyber-world. IoT networks are used health monitoring, utility bill generation (smart metering), tracking, sensing of environments and so on. As a result, researchers have a great interest in this constantly developing and advancing field. Despite the huge research progresses made in different areas of IoT applications, lots more research are needed to handle some recent trends in the field. This paper provides a review of the IoT network as used in a wireless sensor network. The paper review is narrowed to the physical layer of the IoT network and mainly on providing connectivity between the IoT devices at the physical layer.

Wireless sensor IoT network was mostly battery powered. The batteries have limited energy. So, once the batteries of some key nodes are exhausted, the network no more performs its function. The network can continue its function byreplacing the dead batteries of the sensor nodes with new ones. However, it is not always easy to change the batteries as some IoT devices may have been deployed in unfriendly or inaccessible areas such as in a bush for weather forecasting and/or detection of fire incidents. As a result, most researches on IoT network focus on ensuring connectivity using minimum nodes energies to maximize the networklifetime.

Extending network lifetime via minimizing energy usage is normally achieved through either of the following methods: minimum energy routing or clustering (Heinzelman, Chandrakasan, & Balakrishnan, 2000). In minimum energy routing, each sensor node sends its sensed data to another sensor node nearest to it. The receiving node collects the data,aggregatesitwith its own sensed data andthentransmits the aggregated data to another node in the direction of the sink. Aggregation and transmission continue until the data reach the sink. This method is adopted to prevent low power sensor nodes from long-distance communication to the base station (BS) which drain their batteries quickly, resulting in a low network lifetime (Asha & Gowrishankar, 2018). Most research activities on minimum energy routing focus on improving the quality of data aggregation. An alternative to providing ubiquitous connectivity in wireless sensor networks is using clustering. In clustering, the entire network is divided into clusters. Each cluster consists of sensing nodes and a cluster head (CH). The CH is responsible for receiving data from the sensor nodes via one-hop or multi-hop communication; aggregate and transmitting the aggregated data to the BS. In some scenarios involving hierarchical clustering, the CH in a cluster aggregates and forward to another CH. The latterCH may transmit to a base station or another CH until the data finally reaches the sink. So, the energy of the CH is critical to the network lifetime because its energy exhaustion rate is faster than those of other nodes. So, research on clustering focuses on algorithms for the selection of CH among other nodes to improve network life time, decrease latency and improves network efficiency.

Literature Survey

LEACH (Heinzelman et al., 2000) is a famous clustering algorithm for the formation of clusters and selection of CH inwireless sensor networks. The selection of a CH in LEACH was done in a random pattern, without consideration of residual energies of sensor nodes. Moreover, LEACH considers similar sensor nodes, hence suitable for only homogenous networks. As a result, the network performance of a heterogeneous network employingtheLEACH protocol is poor. Besides, to provide coverage in a big network, hierarchical clustering algorithms were proposed using the idea of the LEACH by proposing ways of overcoming the drawbacks of LEACH. In the process, several variants of enhanced versions of LEACH were developed including(Usha Kumari & Padma, 2019), (Shan et al., 2013),(Khadim, Maaden, Ennaciri, & Erritali, 2018),(Abidi & Ezzedine, 2017),(Purkar & Deshpande, 2018), and (Zhang, Liu, & Liu, 2018)and so on as summarises in Table 1.

Due to difficulties in replacing batteries of wireless IoT networks, researchers have recently gained interest in rechargeable-battery wireless sensor networks(Li, He, Fu, Chen, & Chen, 2018a). The new network paradigm, wireless rechargeable sensor networks (WRSN) are not energy limited (their batteriescan recharge), the available solutions based on the LEACH and its variants are inappropriate for it. Moreover, providing ubiquitous connectivity has become more challenging because nodes need to devote some of their operation times to sensing and some other times to recharge their batteries. The benefits of WRSN include:(1) reduction in system cost as batteries contribute greatly to overall system cost especially for large networks; (2) Allows deployment of sensors to inaccessible areas as periodic replacement of batteries is unwarranted; (3) enables perpetual lifetime for sensing and communication as interruption when replacing depleted batteries of energy-limited nodes no longer exist. An example of a wireless sensor network with a rechargeable battery is shown in Figure 1. The description consists of sensor nodes in clusters with their associated CHs. A sink station and a service station are located outside the sensing region. A charging car occasionally leaves the service station in a predetermined path to recharge the batteries of the nodes in each cluster and return to the service station.

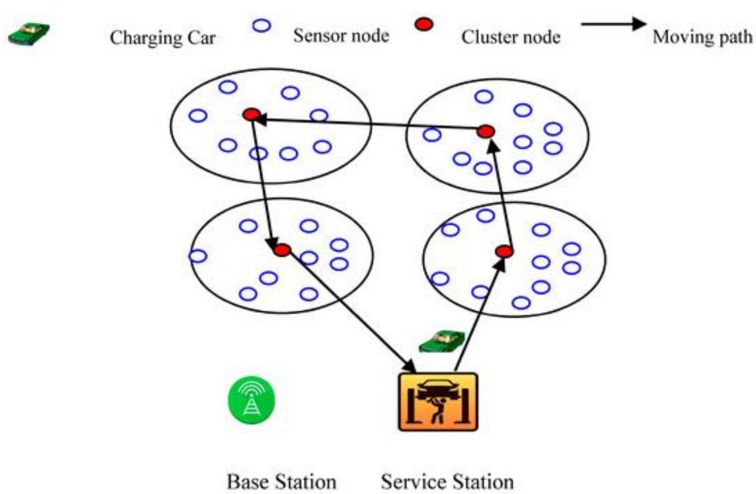

Figure 1: An example of a network architecture for a wireless rechargeable-battery sensor network (WRSN).(Wang, Kong, Wang, & Wang, 2017)

The new network model requires wireless charger deployment to recharge the various sensor nodes in a network. Due to advancements in charger technology, wireless chargers with omnidirectional and directional antennas are now available. Beam steering antenna arrayscould also be used in WRSN but with increased complexity and increase cost, thanks to the availability of Powercast: TX51901(Greene, 2017).

Several approaches have proposed optimal deployment of wireless chargers having omnidirectional or direction antenna in a network for recharging sensor nodes under various constraints. (Jiang et al.,

2012) propose an algorithm for providing wireless power transfer to both a point and along a path when the sensor nodes are equipped with an omnidirectional antenna. A mobile charger that travels to recharge depleted sensor nodes has been considered in (Fu, Cheng, Gu, Chen, & He, 2016). It tried to minimize charging delay from the charger to a sensor node charging at a time. The delay was minimized such that the sensor node energy after recharging is above a threshold (energy for the node to perform sensing and communication task). Placement and orientation of directional wireless chargers to charge directional sensor nodes such that charging utility is maximised has been considered in (Chen et al., 2018). The goal is to find an optimal orientation for a charger such that the charging utility is maximized. The problem ofwirelessenergyreplenishmentof nodes has also been considered in (Yu, Dai, Liu, & Tian, 2018). It considered a fixed number of directional wireless chargers and candidate positions to determine the placement position and orientation angle for each charger under connectivity constraint for wireless chargers such that the overall charging utility is maximised. Other approaches such as (Dai et al., 2016) considered the safety level of electromagnetic waves from wireless chargers. It proposed placement positions for wireless chargers such that the aggregate electromagnetic radiation at a point within the network is below a certain safety threshold. However, these papers proposed solutions on how to deploy wireless chargers without looking at the operation of the sensor nodes.

Sensor nodes with rechargeable batteries need to operate in two modes: recharging from the wireless charger and performing sensing and communication. Due to the requirement of low cost for WSN, the nodes cannot perform both duties concurrently. Hence a node needs to devote some of its operation times to recharge its battery and other times to performing sensing and communication. Hence selection of suitable operation state by a node needs to be done efficiently to avoid reducing the network lifetime. Moreover, some researches have proposed algorithms for efficient selection of operation states of nodes with rechargeable batteries. Since Powercast designed wireless chargers separately from sink stations, optimal co-deployment of stationary wireless chargers and sink stations has been proposed in (Li, Fu, He, & Sun, 2017) by using the interdependent relationship between data flow and energy flow. The deployment minimises the number of chargers and sink stations while sustaining data sensing and transmission by finding the optimal placement of wireless chargers and sink stations as well as defining the routing path of each sensor node.

Table 1: Summary of some literature Reviewed

Research Work	Technique	Limitation
(Usha Kumari & Padma, 2019)	Similar to LEACH: nodes report their attributes to BS that does the selection of CH	Centralized and too much overhead for the BS
(Shan et al., 2013)	LEACH approach in addition to consideration of residual energies and distances of nodes in a cluster when choosing a CH	Not suitable for a heterogeneous network.
(Khadim et al., 2018)	Based on the LEACH approach. Only that the BS selects a node as CH if it has enough energy to support a certain number of rounds	Centralized and not suitablefor heterogeneous networks.
(Abidi & Ezzedine, 2017)	LEACH approach in addition to consideration of residual energies, distances of a node and the number of neighboring nodes in a cluster when choosing a CH	Not suitable for heterogeneous networks.
(Purkar & Deshpande, 2018)	Considered heterogeneous network. BS elect CH based both node quality index	Centralized since only BS can elect CH
(Zhang et al., 2018)	selection of CH based on local density and distance using data point approach	Not suitable for heterogeneous networks.

Optimal operation state scheduling in RF-Powered internet of Things has been proposed in(Li, He, Fu, Chen, & Chen, 2018b). Since simultaneous working and harvesting is not possible due to the low-cost requirement of IoT devices, optimally scheduling of IoT devices to either working or recharging wirelessly, a challenge towards achieving a certain network utility (throughput, latency, etc) is needed. It was observed that in a small network, where data from a sensor node can reach a sink via one-hop communication, the network topology does not change with operation state. However, for a large network where data from a sensor node reaches a sink station via multi-hop communication, the network topology is dynamic due to coupling between operation state scheduling with the network topology (routing path) as shown in Figure 2. As in Figure 2, the routing path towards the sink in time slot 1 when node 4 is alive is different from the routing path in time slot 2 when the battery of node 4 is depleted of energy. As a result, a state scheduling algorithm (SSA) to maximize network throughput was designed to decouple the primary problem by defining a dynamic energy threshold vector that schedules a node to a desirable stateaccording to its energy level.

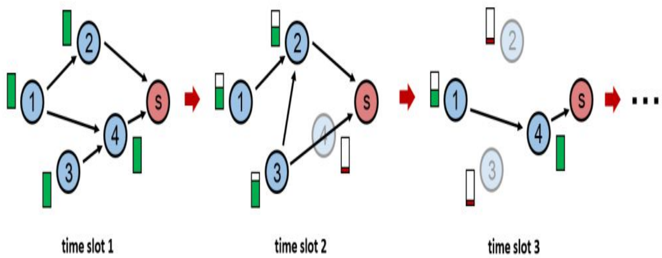

Figure 2: State scheduling and time-varying topology in a partial wireless rechargeable sensor network.(Li et al., 2018b)

Other approaches use mobile wireless chargers within a sensor network.Such approaches include(Lai & Hsiang, 2019), (Zou et al., 2017) and(Shu, Shin, Chen, & Sun, 2017).The goal in mobile charger approaches is to find an optimal path to be followed by a mobile charger and also optimal stop locations along the path such that sensor nodes are efficiently recharged within a recharge duration.

Future Research Direction

With the new wireless sensor network model, WRSN, researches will most likely be focused on developing algorithms for efficient selection of operation states (battery recharging or sensing and communication task) of sensor nodes. The minimum energy routing approach will be employed in smart homes and other areas where maximizing network throughput is the main concern, at the same time ensuring efficient operational state selection. On the other hand, the clustering approachis suitable in areas requiring low network latency. Whichever network deployment approach is selected, ensuring efficient operational state scheduling is highly important toward the practical realization of WRSN. Moreover, since TX51901 wireless charger has beamforming capability, researches are needed to investigate factors that can enhance network performance gain such that the additional cost of deploying such complex antenna arrays can be overlooked.

Conclusion

Wireless rechargeable sensor networks (WRSN, a new network paradigm, proposed to overcome some drawbacks associated with wireless sensor networks (WSN). Unlike in WSN, the batteries of nodes in WRSN can be recharge hence mitigating network unavailability time due to the replacement of exhausted batteries encountered in WSN. However, the existing approaches used in maximising network lifetime in WSN are unsuitable for WRSN. Besides, WRSN presents a more complex problem of how to ensure ubiquitous connectivity in addition to ensuring maximum network lifetime. This paper reviewed recent literature on ensuring the connectivity of the internet of things at the physical layer and presented possible future research directions for WRSN.

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