Data Collection System for Mobile Cellular Network System

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***Abstract*: A critical issue for data gathering in wireless sensor network (WSN) is the formation of energy holes near the sinks. Sensors near the sinks have to participate in relaying data on behalf of other sensors and thus will deplete their energy very quickly, resulting network partitioning and limitation of network lifetime. Data gathering is a fundamental task of WSN. In WSN, data gathering using multiple mobile sinks reduces and balance energy expenditure among sensors. In multiple mobile sinks, the energy efficient data collection and transmission is hot research topic. The Multiple Mobile Sinks Energy Efficient Data Collection (MSE^2DC) scheme for query-driven data delivery in tree topology WSN and MCN system. In this system, User Equipment (UEs) are equipped with WSN air-interface. The UEs acts as mobile gateways to control the WSN data gathering and provide backhaul data links. The WSN sensors are purposely activated for data delivery. By adopting the MSE^2DC only necessary sensors should be activated for data collection and transmission while the other sensors should be in the sleeping state to save energy. In this paperMSE^2DC scheme multiple UEs are equipped with WSN air interface and acts as mobile gateway for data delivery in mesh-topology and in this scheme the UEs consume less energy compared to the existing scheme. This paper introduces multiple UE's strategies and discusses their advantages and disadvantages in comparison with existing strategy. Performances of these strategies are analyzed and analysis results will be presented in this paper, it has been observed that the proposed strategy exhibit better performance compared to the conventional strategy.**

Keywords— WSN, MCN, Mobile UEs, Data delivery.

I. INTRODUCTION

In WSNs, mobile sinks have been proposed as a solution for data collection to geographically balance the energy consumption among the sensors throughout the network [1-3]. This not only solves early death problem of the one-hop neighbors of the sink but also extends the network lifetime by distributing the responsibility of relaying data to the sink among many sensors in WSN [4-5]. However, the data collection via mobile sinks results in high latency of data collecting because of the frequently updating to topology and routing [1]. Nowadays, the development of new technologies and the standardization of new air interfaces for wireless networks increased the interest of researchers toward Wireless Hybrid Networks (WHNs) [6]. This paper in particular refers to WSN and MCN convergence architecture. The convergence is a very popular deployment solution to extend the service for both two networks. MCN can enlarge its applications by managing or controlling WSN devices for monitoring or data collection, while the WSN can utilize the MCN to share its information with other networks immediately. Mobile devices with cellular interfaces act as mobile gateways which is one of the potential options to converge MCN and WSN. In most convergence applications, the cellular network entities such as UEs are involved into the WSN and act as gateways/sinks to offer more convenient and efficient services [7].

In conventional data collection mechanism in convergence scenario, the mobile UE moves to a place and activates the sensors in its one-hop range to collect data. These activated sensors activate their child sensors for data collection via traditional multi-hops methods. With the movement of mobile UE, the same sensors may be frequently activated for data collection. However, in most use cases such as air/soil/water pollution monitoring, the collected data could be valid as a reference during a pre-configured period and there is no need to reactivate the same sensor to collect data in this period. Otherwise, the unnecessary frequent activations results in extra energy consumption and then shorten the sensors' lifetime.

In most convergence applications, the MCN entities such as UEs are involved into the WSN and act as gateways to offer convenient and efficient services [7]. The mobile UE moves in WSN area and activates the sensors in its one-hop range to collect data. These activated sensors activate their topological child sensors for data collection via traditional multi-hops methods. With the movement of mobile UE, this procedure repeats at different physical locations. If the WSN's topology is fixed, it is highly possible that some sensors may be repeatedly activated even the mobile UE stops at different physical locations. However, in most use cases such as air/soil/water pollution monitoring, the data collected from a sensor could be valid as a reference during a pre-configured period and there is no necessary to reactivate this same sensor to collect data in this period. Otherwise, the frequent activations results in extra energy consumption and then shorten the sensor's lifetime. Moreover, if there are multiple mobile UEs acting as mobile gateways to collect data simultaneously in the same WSN area, the possibility of frequent activation of same sensors will significantly increase since the sensors may be activated by different mobile sinks. Hence, the convergent interactive control and joint optimization technologies of MCN and WSN to energy-efficiently collect/transmit data is a critical problem and need to be researched and developed.

In this paper, to solve the aforementioned problems, we propose a multiple sinks energy-saving data collection scheme (MSE^2DC) in WSN-MCN convergence system. We first provide an overview of related work of mobile sink data gathering in Section II. Then, in Section III, we introduce the network model and describe proposed MSE^2DC scheme in detail. In Section IV, we discuss and analyze the simulation results. Finally, we conclude the work in Section V.

II. RELATED WORKS

This section reviews the existing data collection approaches in WSNs with mobile sinks.

In sparse sensor networks where the path is random [1], the mobile sinks are often mounted on some people or animals to collect interested information sensed by the sensors. However, latency is increased because a sensor has to wait for a mobile sink before its data can be delivered. Liu et al. in [3] proposes aproactive data reporting protocol, Sink Trail, which achieves energy efficient data forwarding to multiple mobile sinks with broadcasting sink location messages. But this kind of data collection schemes is undesirable, especially when the sensor network scale increases, as frequent message flooding will cause serious congestion in network communication and significantly impair the sensor network lifetime.

Path-constrained sink mobility is exploited in [8], a mobile sink is installed on a public transport vehicle which moves along a fixed path periodically. All sensors can only transmit data to the single mobile sink in one-hop mode which maybe infeasible due to the limits of existing road infrastructure and communication power. Gao et al. in [2] propose a novel data collection scheme with sink moving along a constrained path, called Maximum Amount Shortest Path (MASP), which assigns the members out of the range of the sink to the corresponding sub sinks within the range of the sink, thus improving the network throughput. However, this kind of data collection schemes is based on the condition that the mobile sink has a planned mobility path or the path can be accurately predicted.

The data collection algorithms based on path-controllable mobile sink focus on how to design the optimal trajectories of mobile sinks to improve the network performance. Mobile element scheduling problem is studied in [9], where the path of the mobile sink is optimized to visit each sensor and collect data on the constraint of buffer and data generation rate of each sensor. A rendezvous-based data collection approach is proposed in [10] to select the optimal path due to the delay limitation in WSNs with a mobile base station. The mobile element visits exact locations, called rendezvous points, according to the proposed schedule to collect data. The rendezvous points buffer and aggregate data originated from the source sensors through multi-hop relay and transfer to the mobile element when it arrives. But there is a main disadvantage for this kind of data collection schemes which is bad scalability. Once the network changes, the path of mobile sinks need be changed.

In order to solve the problem of frequent activation, Yin et al proposes an Energy-Efficient Data Collection Scheme (E^2DCS) [11, 12] to collect data from the sensors when single mobile UE moves randomly in WSN, as shown in Figure 1

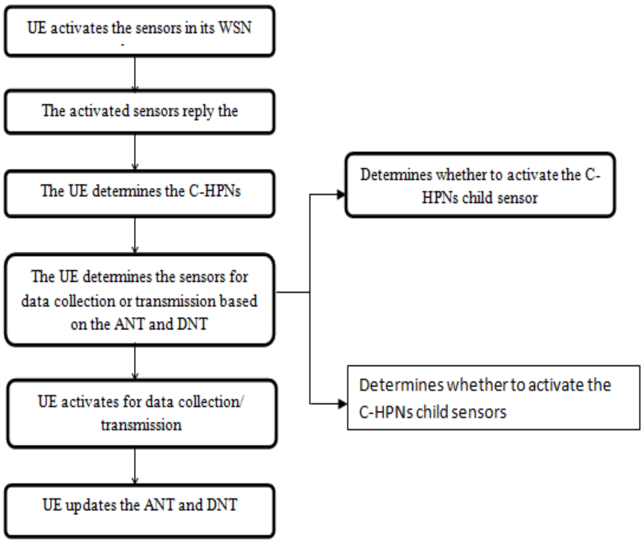

Fig. 1. The main steps of E^{2}DCS.

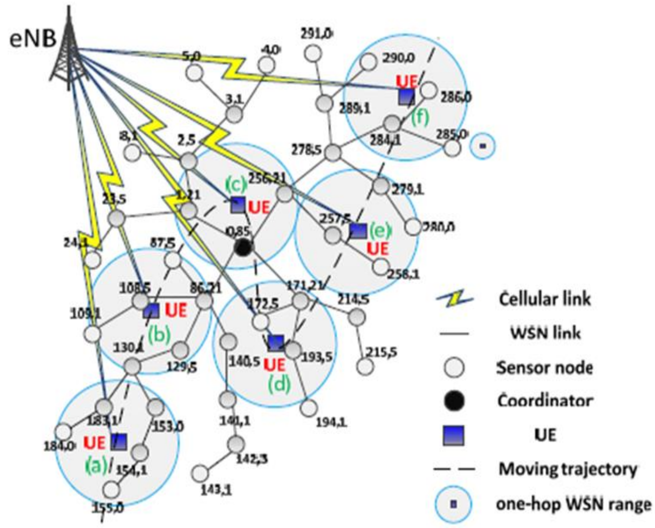

Fig. 2. The scenario of data collection via mobile UEs.

Based on the E^{2}DCS, only necessary sensors should be activated for data collection/transmission while the other sensors could keep sleeping to save energy. However, in realistic applicative scenario, only one single mobile UE in the WSN area for data collection is not reasonable, there may be multiple mobile UEs acting as gateways to collect data simultaneously. In this scenario, if each mobile UE individually adopts E^{2}DCS to collect data, the frequent activation of the same sensors by different UEs is inevitable.Involving the coordination among the mobile UEs is necessary, which can not only avoid the frequent activation of the same sensors for data collection but also some appreciated mobile UEs can act as mobile gateways to overhear and directly transmit the collected data to the MCN instead of activating some WSN sensors for data transmission. The MCN entity such as base station (BS) coordinates the multiple mobile UEs to determine which mobile UEs can assist to collect or transfer data from which WSN sensors, and keeps the other sensors sleeping to save the energy consumption

III. NETWORK MODEL AND PROPOSED SCHEME

The proposed MSE^{2}DC is supposed to work in WSN-MCN converged networks. The WSN sensors are deployed randomly and networked based on tree topology. The multiple mobile UEs act as mobile gateways and randomly move in the WSN area to collect data from the sensors and transfer the collected data directly to the MCN. For each data collection stop, the BS coordinates the information from the multiple mobile UEs and determines the mobile UEs and the WSN sensors for data collection and transmission. The scenario of multiple mobile UEs data collection is illustrated in Figure 2.

There For simplicity and without loss of generality, we make the following assumptions for the network model:

- The WSN sensors are networked based on IEEE 802.15.4 [13] and ZigBee [14] tree topology.
- All the sensors are initially in sleep state, and go to sleep after finishing the data collection or transmission.
- The sensors are allocated the address based on the allocation mechanism defined in ZigBee specifications, and the UE is aware of the address allocation mechanism.
- Once knowing the addresses of WSN sensors, the UE can recognize the filiations of the sensors based on the allocation mechanism defined in ZigBee specifications.
- The UEs are equipped dual interfaces: WSN interface and MCN interface. UEs synchronized with the WSN each time when stop for data collection.
- The collected data should be valid for a period of time. During this period, there is no need to recollect the data from the same sensors.

The main steps of MSE^{2}DC scheme are shown in Figure 3. If one mobile UE stops for data collection, it activates the sensors in its one-hop range with its WSN interface. The activated sensors reply their addresses to the mobile UE. The mobile UE determines the current highest parent nodes (C-HPNs) based on the filiations among these sensors. Then the mobile UE sends a REQUEST message including its C-HPNs to the BS to ask for data collection assistance. We called this request mobile UE as RU and its C-HPNs as RCHPNs.

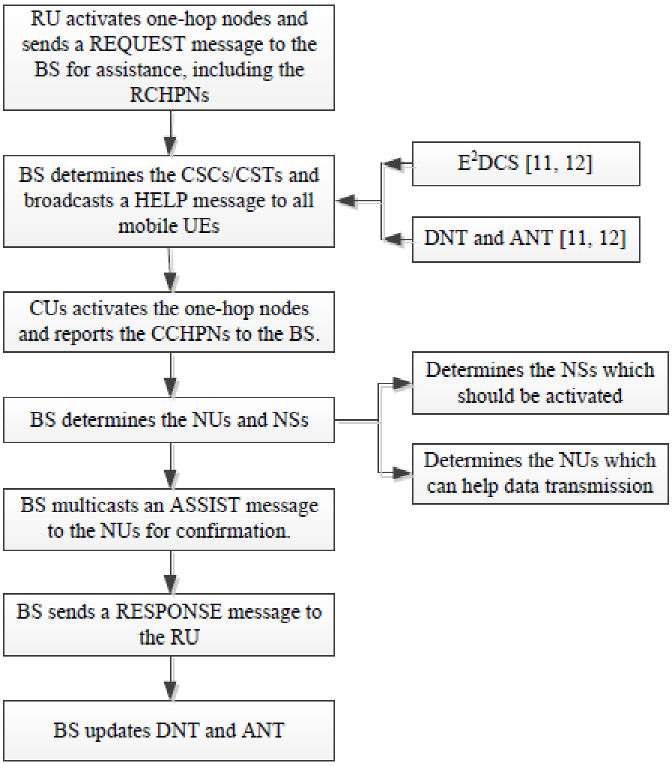

Fig. 3. The main steps of MSE^{2}DC.

In MSE^{2}DC, same as E^{2}DCS in [11, 12], the BS maintains two tables, depreciated node table (DNT) and appreciated node table (ANT). By adopting the E^{2}DCS in [11, 12], the BS determines the candidate sensors (CSs) which may be activated for data collection or transmission based on the RCHPNs and the information in DNT and ANT. Then, the BS broadcasts a HELP message to all mobile UEs in the WSN area. Once received the HELP message from the BS, if the mobile UEs would like to provide the help of data transmission, the mobile UEs stop and activate the sensors in their one-hop range. They determine the C-HPNs and report the C-HPNs to the BS, respectively. We called these mobile UE as candidate mobile UEs (CUs) and the reported C-HPNs as candidate C-HPNs (C-HPNs).

The flow chart of the determination of NUs and NSs could be further discussed in detail in Figure 4. The purpose is to minimize the number of CSTs and make use of mobile UEs to transfer the collected data if possible.

After received the CCHPNs reported by the CUs, the BS first recognizes the topological relationship between the RCHPNs and the CCHPNs in the tree topology.

Case 1: If there is no relationship between the RCHPNs and the CCHPNs, these CCHPNs are deprived of the candidature.

Case 2: If the CCHPNs are the topological parents of the RCHPNs, all the collected data could be transferred by the RU and these CCHPNs can not provide assistance for the data transmission and may be deprived of the candidature.

Case 3: If the CCHPNs are the topological child sensors of the RCHPNs, these CCHPNs should be further distinguished based on the topological relationship with the CSCs/CSTs.

If the one-hop parent node of the determining CCHPN is a CSC, it means that this one-hop parent node originally must be activated for data collection. Hence, this CCHPN may not be helpful to reduce the number of CSTs and could be deprived the candidature.

Based on the physical location of RUs and CUs, the CCHPNs and RCHPNs may be related topologically. For example, as shown in Figure 1, the UE1's RCHPN #140 is the topological parent of the UE2's CCHPN #141. After recognized the topological relationship between the CCHPNs and the RCHPNs, the BS determines the necessary mobile UEs (NUs) which can give a helping hand for data transmission. Then, the BS determines the necessary sensors (NSs) which should be activated based on the NUs and the information in ANT and DNT. (This step will be discussed in detail later on)

After the determination, the BS multicasts an ASSIST message including the corresponding CCHPNs to the NUs to confirm the assistance and sends a RESPONSE message including the NSs to the RU. Finally, the BS updates the information in DNT and ANT.

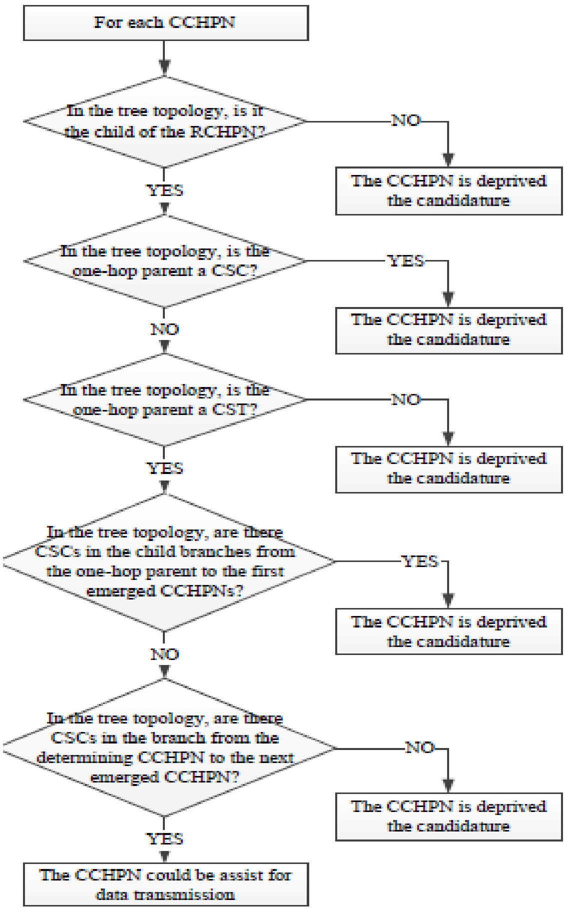

Fig 4. Flowchart of CCHPN determination

After received the RESPONSE message, the RU begin to activate the NSs for data collection. After received the ASSIST message, the NUs begin to collect data from the corresponding CCHPNs and transmit to the MCN. The other mobile UEs do not receive the message can continue their primary movements.

IV. SIMULATION RESULTS

In this section, a series of numerical simulations are implemented by using Matlab to verify the energy saving gains of the proposed MSE^{2}DC scheme and E^{2}DCS [12], comparing to the conventional scheme that the mobile UE randomly moves and freely stops for data collection without considering time-validity.

We construct a 1200m*1200m WSN area, in which 1000 sensors are randomly deployed and networked based on tree-topology. The WSN sink is in the middle of the area. There are 20 mobile UEs moving randomly in the WSN area to collect data from the sensors and their velocity is 60 m/min. The UEs initially locate randomly in WSN area and stop 50 times for data collection. The time intervals between sequent two data collections are random and the collected data could be valid before the data validity period expired. In our simulation scenario, we assume that there are random several mobile UEs stop to collect data simultaneously and all the other mobile UEs would like to provide assistant.
A parameter GE is introduced to evaluate the energy saving gains:

$$GE= (Nb – Np)/ Nb$$

Where Nb is the number of activated sensor of the conventional scheme and Np is the number of activated sensors of the proposed MSE^{2}DC scheme or E^{2}DCS scheme. In the simulations, the GE is evaluated by varying the data validity period. For each case, 100 simulations are implemented to get a average value of GE.

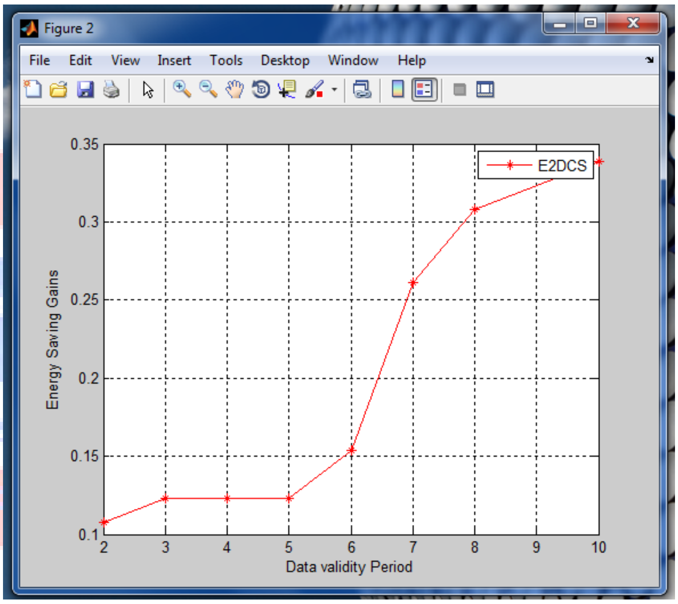

Fig 5. The value of GE when the data validity period varying of E^{2}DCS.

We also simulate the scenario of varying the data validity period but keeping the time interval fixed. For simplicity, we assume that the time interval is 3 min and the data validity period varies among 4~10 min. Figure 5 shows the simulation result, where the x-axis is the data validity period and the y-axis is the value of GE.

We can find out that the values of GE of both scheme increases as the data validity period increases. It is easy to understand that the number of data collections increases as the data validity period increases if the time interval is fixed. It means that collected data would have been valid during more data collection. It results in fewer sensors should be activated at each data collection for data collection and transmission, which obviously results in higher values of GE for both schemes.

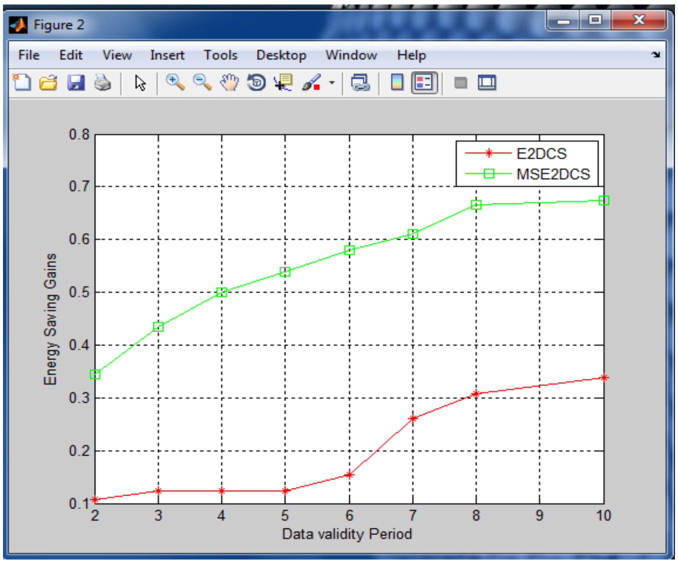

Fig 6. The value of GE when the data validity period varying

As illustrated in Figure 5, the MSE^2DC scheme can less activate almost 70%-80% sensors comparing the conventional mechanism; and less activate almost 60% sensors comparing the E^2DCS scheme. As the MSE^2DC scheme can make use of some appreciated mobile UEs for data transmission to avoid activating the sensors, the values of GE of the MSE^2DC scheme is obvious higher than that of the E^2DCS scheme.

We now simulate the scenario of varying the time interval and data validity period simultaneously. We assume that the data validity period varies among 4~10 min and the time interval randomly varies among 1~[(data validity period)-1]min.

V. Conclusion

In this paper we proposed a MSE^2DC scheme in WSN-MCN system. Only tree topology is discussed since the MSE^2DC should take the topological relationship of sensors into account to determine and activate the sensors. By adopting the scheme necessary sensors should be activated for data collection/transmission while the other sensors should be sleeping to save. On the other hand, MSE^2DC introduce additional signaling overheads for the mobile UE to inform/activate the necessary sensor nodes. Moreover, MSE^2DC scheme makes use of some mobile UEs for data transmission which increases the UEs energy consumption. However, these disadvantages are minor comparing the significant advantages.

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