Movement Direction Based Path Selection Strategy in Converged Cellular and Wireless Sensor Networks

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***Abstract*—Wireless sensor networks have been applied in many service application areas, which consist of numerous autonomous sensor nodes with limited energy. In order to optimize the wireless sensor networks performance and meanwhile expand the cellular network's service applications, mobile cellular networks and wireless sensor networks are evolving from heterogeneous to converge. However, the sensor nodes need to be informed the mobile sink's location for data collection purpose. Unfortunately, frequent location updates from multiple sinks can lead to both excessive drain of sensors' limited battery supply and increased collisions in wireless transmission. In this paper, we describe the movement direction based path selection strategy which adopts the grid structure and provides an efficient mobile sink's location updates approach. When the sinks have mobility, they only inform their current locations to the specific nodes on the previous path instead of the source nodes. We evaluate the proposed method through both analysis and extensive simulations. The results show that our proposed theory not only provides an energy-efficient location update approach, but also generates a minimal delay path for data dissemination.**

Keywords-Wireless Sensor Networks, mobile sink, location update, routine, movement direction

I. Introduction

The developments of wireless communication and Micro Electro Mechanical Systems (MEMS) technologies have made it possible for the deployment of large-scale Wireless Sensor Networks (WSNs) [1]. WSNs can be used for a wide range of applications in the scientific, commercial, medical, military battlefield, industry control, traffic control, and ambient conditions detection areas [1-3].

Nowadays, the convergence of WSNs and Mobile Cellular Networks (MCNs) emerged as a hot research topic is a very popular deployment solution to extend the services for both two networks. MCNs can enlarge its applications by managing or controlling WSN devices for monitoring or data collection, while the WSN can utilize the telecommunication network to share its information with other networks.

In conventional WSN, the data is collected by the sensors and transferred to the sink via multi-hop. And proposed mobile data sinks [4-5] have become a good solution comparing with static sinks [6-8] for data collection to geographically balance the energy consumption among the sensor nodes throughout the network. Mobile device with cellular interfaces acting as mobile sink is one of the potential options to converge WSNs and MCNs. In most convergence applications, the cellular network entities such as user equipment (UE) are involved into the WSN and act as the mobile sinks to offer more convenient and efficient services. Also in the third generation partnership project (3GPP), the mobile sink between the cellular network and capillary network (e.g. WSN) has gained extensive attractions by the operators [9].

However, sink mobility brings new challenges to data dissemination in large sensor networks. Mobility suggests that information about each mobile sink's location be continuously propagated to the source nodes in order to keep all the source nodes informed of the direction of forwarding future data reports. In the two-tier data dissemination (TTDD) protocol [10], the multiple mobile users (sinks) disseminate their queries and receive data from the source nodes through the grid routing architectures. However, the two-tier forwarding is best suited to deal with "localized" mobility patterns. When the sink moves outside of the current grid's range, it has to send the message upstream periodically and the position information via its new immediate dissemination node in order to receive data continuously. This procedure causes rapid power consumption and induces inefficient resource usage. In the anchor location service (ALS) protocol [11], when the sink has moved, it will select another new grid node as the sink agent and this new sink agent in turn notifies the previous sink agent about its current location. Compared with the TTDD mechanism, ALS protocol reduces the signaling overhead. But still, the ALS chain updating is fully based on sink's movement track, which might not be very efficient in most of time, i.e., shorter path or direct exists. In the energy-efficient sink location service protocol [12], when any sensor node that forwards data realizes its adjacent sensor node whose number of hops from the source node is less than half of its number of hops from the source node, it will select the adjacent sensor node as its uplink to change the path of forward data. In the method, although the detour problems can be avoided when the sink arrives at some area, the sensor node has to memorize all the adjacent nodes' number of hops from the source node, which needs a lot of memory consumption and processing capability.

We consider a mobile sink based WSN where all sensor nodes are stationary and mobile sink has both WSN mode and cellular mode, meaning that mobile sink can communicate with WSN and cellular network. The grid structure is adopted to illustrate the proposed movement direction based path selection

(MDBPS) method. This will significantly reduce the sink's location update overhead and save network energy.

The rest of the paper is organized as follows. In Section II, the system model of the convergence of WSNs and MCNs will be described. In Section III, we will depict the MDBPS procedure in detail. In Section IV, simulation results are presented, which compare the MDBPS method with the TTDD and ALS protocol. Finally, several pertinent remarks are given in Section V to conclude the paper.

II. SYSTEM MODEL

In the convergence concept, all sinks are dual-mode and have both WSN and cellular network interfaces as illustrated in Fig. 1. A group of wireless sensor nodes construct the data detecting plane, while the sink and base station (BS)/cellular network is responsible for the control of the WSN network. The WSN is controlled indirectly by the BS/cellular network through the mobile sink. The mobile sink can provide the access for the WSN nodes, and forward the detected data to the backhaul networks servers. Communications between WSN and cellular network are conducted via a dual-mode mobile device [13].

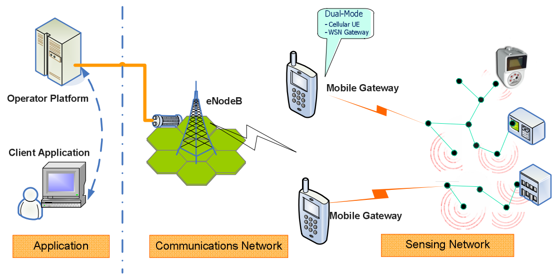

Figure 1. Converged network architecture for MCN and WSN

The primary objective of the integration is to design a WSN fixed/mobile sink including transmission path selection, mobile sink management, activation/deactivation and corresponding control signaling design for connectivity-oriented, lifetime-oriented and hybrid deployment. A mobile terminal acting as a mobile sink for WSN transmits the detected data to backbone database under the assistance of eNB (or any other feasible network control element). Therefore, this mobile sink is required to provide wireless interface(s) to other sensor nodes as well as the air interface of a mobile network system (e.g., 3G/3GPP/WiMAX) to the existing cellular network infrastructures. The mobile sink shall be able to manage the WSN network under the assistance from the cellular network. In order to simplify the description, a grid-based WSN structure, which is widely adopted in different service applications, is exploited in the later sections. As the queries from the multiple mobile sinks are confined within the local grid, thus avoiding excessive energy consumption and network overload.

III. THE MDBPS METHOD

As described in Section 2, the converged network can improve the WSN transmission efficiency. In this section, we will illustrate the MDBPS method in the network architecture.

With the grid structure, the sensor nodes closest to the grid points could be elected agent nodes or the agent nodes could be pre-deployed on the grid. A query from a sink traverses two tiers to reach a source. The lower tier is within the local grid square and the higher tier is made of the agent nodes on the grid. In practice, it means that the data collection is via agent nodes to the mobile device. Inside the grid, sensor nodes send the data to the agent node in a conventional way as illustrated in Fig. 2. For the convenience of illustrating and comparing with the TTDD protocol, the dissemination paths on the grid structure are ruled horizontal and vertical. Upon detection of a stimulus, the source node disseminates the data to the nearest agent node, which forwards the data to the adjacent agent node by multiple hops until to the mobile sink.

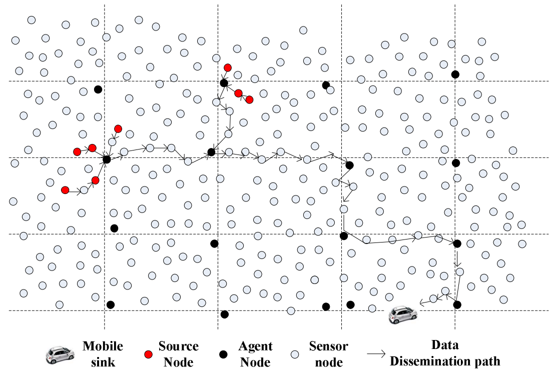

Figure 2. Grid based WSN

Based on the grid structure, a method of dynamically updating path based on the direction information in grid structure for mobile sink is proposed, i.e., movement direction based path selection method. The detail of the proposed routine initialization and updating method for the grid structure is described hereafter step by step with a few assumptions as follows:

- All the sensor nodes are stationary;
- The source node and the sink node selects their nearest agent node as their agent node;
- Each agent node knows its own location and covers a number of sensor nodes in a pre-defined area;
- The deploying and optimizing of the grid structure is out of the scope of this study;
- There is no failure on the data dissemination phase (i.e., data dissemination failure is out of the scope of this report).

A. The MDBPS Procedure

Based on those above assumptions, the proposed MDBPS procedure is depicted step by step hereafter.

Step 1: After the network employing and agent node placing, the coordinate for each agent node shall be set in a systematic way as illustrated in Fig. 3. Each agent node has a unique coordinate for a certain period. It should be possible to reset the coordinate if any changes in the WSN network, e.g., increasing/decreasing number of agent nodes etc.

Step 2: The mobile sink floods the query messages within the agent area and finds the nearest agent node P1 as illustrated in Fig. 3. Meanwhile, agent node P1 starts to broadcast its own position represented by the coordinate (1, 0) and mobile sink's rough movement direction (the accuracy of the direction is dependent on the number of bits used), average speed and initial moment.

Step 3: After receiving the agent node P1's query message, the source agent node P0 forecasts that the agent node P2 is the closest agent node for the mobile sink's next moment.

Step 4: Once the source agent node and destination agent node is determined, an optimal path could be selected based on the available information among multiple potential paths based on some pre-defined principles.

When the sink agent node P2 is in the west of the source agent node P0:

a) If the movement direction is towards east, southeast or northeast, the initial path from the P0 to P2 requires that the vertical coordinate changes prior to the horizontal coordinate changing as in Fig. 3.

b) If the movement direction is towards west, southwest or northwest, the initial path from the source agent node to the sink agent node requires the horizontal coordinate changes prior to the vertical coordinate changing as in Fig. 4.

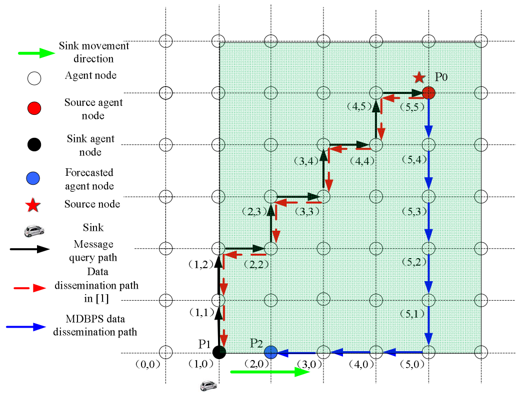

Figure 3. Initial dynamic path selection (a)

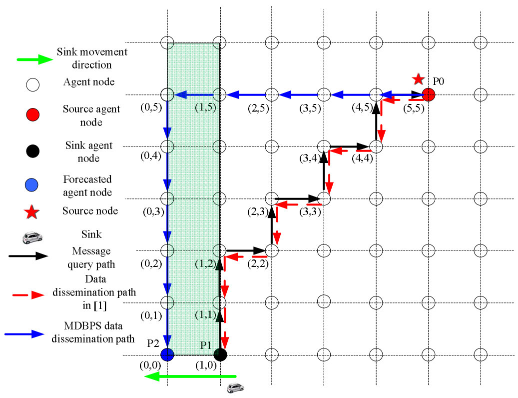

Figure 4. Initial dynamic path selection (b)

When the sink agent node is in the east of the source agent node, the similar steps as described above could be applied.

For the mobile device with medium velocity around 60 km/h, it could be assumed that the query transmission is much faster than the mobile device's speed.

Step 5: After the initial path is built from the source agent node to the sink agent node, the mobile sink might continue to move to another new position P3 as in Fig. 5. As the sink knows the principle of the path creation based on movement direction, the sink's previous agent node coordinate, the source agent node's coordinate and the previous path, the sink is able to update its path towards the new agent node P3. And the new path follows the pre-defined path creation principle as described in Step 4. The mobile sink node is also aware of the joint node if any in the existing path, i.e., P4 (5, 2) in Fig. 5.

As in Fig. 5, the source agent node is P0 and previous agent node is P2. The path creation principle is that the vertical coordinate changes prior to the horizontal coordinate changing. The previous path from the source agent to the sink agent P2 is through the agent nodes whose coordinates are (5,5), (5,4), (5,3), (5,2), (5,1), (5,0), (4,0), (3,0) and (2,0). The new path will utilize the existing path (5,5), (5,4), (5,3), (5,2) and then create the new path (5,2), (6.2). When the sink arrives at P3, it will inform its current position to the agent node (5,2) to form a new optimal path for data dissemination.

Step 6: During the mobile sink position transition period, in case any data has been lost in the previous path between P4 and P2, those data will be temporarily transmitted to the agent node P2. P3 sends its position information via the previous data dissemination path to P2. Then the agent P2 will forward the remaining data packets to P3. The path between the P2 and P3 still follows the previous path but in the reverse order in a pre-defined configurable period *T*, which will not awaken other agent nodes.

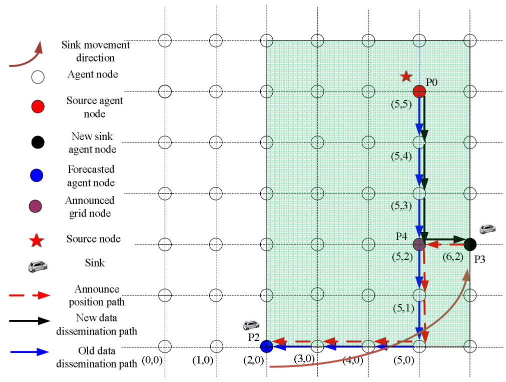

Figure 5. Movement direction based path selection (MDBPS)

B. *The MDBPS Under the Control of eNB for Multiple Mobile Sinks*

If there are multiple mobile sinks, based on the previous sink agent node coordinate, source agent node coordinate and all the sinks' current agent node coordinates, assuming that eNB is aware of the path selection principle, the location of the source and mobile sinks' agent nodes, eNB will determine the potential paths between the source agent node and current sinks' agent nodes. Consequently, the eNB is able to select a most suitable mobile sink to collect the data.

As illustrated in Fig. 6, when UE S1 moves from P2 to P3, UE S2 is arriving at P4 and UE S3 is arriving at P5. The eNB will receive the position information from all the three UEs as well as the source agent node coordinate and the previous data dissemination path from the current sink S1. Based on the above path creation principle (in Fig. 6, the vertical coordinate changes prior to the horizontal coordinates changing), S3 is more suitable than S1 for collecting data. In addition, although S2 is the nearest agent node to the source agent node, selecting S3 as the new sink will awaken less agent nodes based on the previous path. Then the eNB will select the UE S3 as the new sink to collect data continuously.

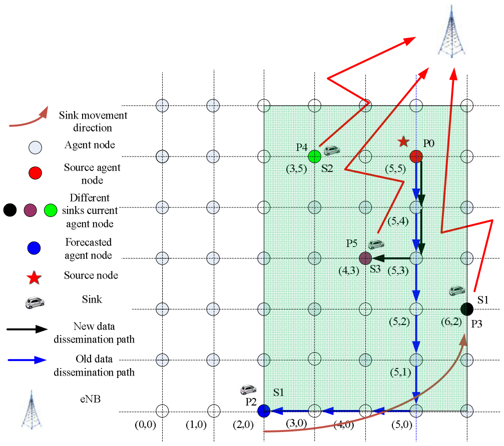

Figure 6. Mobile sink selection based on MDBPS

IV. SIMULATION RESULTS

In this section, we compare the MDBPS method with the ALS and TTDD protocols, in terms of energy consumption for location updates and data communication as well as the delay time which indicates the time from the sink updating its current location to receiving the data after it has moved. We implement the MDBPS method using Matlab to evaluate its performance.

In the simulations, we use the following energy model:

$$E_l=\alpha\times n\times h_l \tag{1}$$

$$E_d=\alpha\times n\times N_d\times h_d \tag{2}$$

$$T_d=\beta\times(h_l+h_d) \tag{3}$$

where, E_l and E_d denote the energy consumption for mobile sink's location update and data dissemination from the source node to the sink; T_d denotes the delay time from the sink updating its location to receiving the next data packet after the sink has moved; α and β denote each sensor node's average energy consumption and delay time for receiving and transmitting data once, respectively; h_l and h_d, the numbers of grid hops for location update and data dissemination; n, the average number of hops between two agent nodes and N_d, the number of data packets disseminated from one source node to the sink. In order to simulate intuitively, the energy model has ruled the values of α=150μJ, β=0.4ms, n=5 and N_d =1. We also assume that the sink mobility pattern follows the widely-used random mobility model. The main parameters are listed in Table 1. The default simulation environment is in a dimensional 100×100 agent nodes field.

TABLE 1. SIMULATION PARAMETERS

Parameter	Value
Network size	100×100 agent nodes
α	150μJ
β	0.4ms
n	5
N_d	1
Times of a sink's movement	10

We calculate the number of hops for location updating and data dissemination based on the three protocols under the simulation environment, and then compare the energy consumption and delay time among them. Fig. 7 illustrates as the sink moves continuously, the three protocols require to consume the total energy for location update. As Fig. 7 shows, the overhead cost for location update in the MDBPS method approximates to that in the ALS protocol, which both less than that in the TTDD protocol. The reason is that in the TTDD protocol once the sink leaves the range of the current primary agent, the data dissemination path will be reselected via the sink periodically sending query message to the source node, which costs rapid energy. And in the ALS protocol and MDBPS method, the sink only updates its current location to the specific agent node on the previous path which is much nearer than the source agent node, so that they both reduce the energy consumption for the location update.

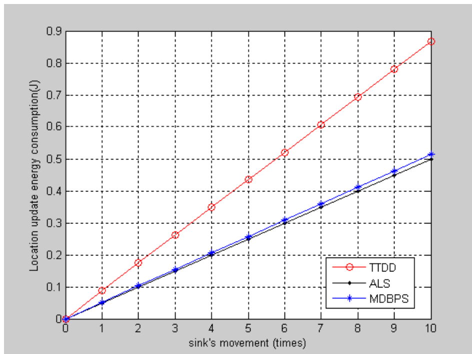

Figure 7. Total energy consumption for location update

As shown in Fig. 8, as the sink moves continuously, the energy consumption of the MDBPS method and the TTDD protocol for data dissemination is less than that of the ALS protocol. The reason is that the formers have formed the optimal paths along the agent nodes from the source node to the sink, while the ALS protocol is designed to allow the chain to have up to l number of links to keep the anchor system intact while tracking the mobile sink. It forms a detour data dissemination path with obvious disadvantage when the number of the sink's movement increases.

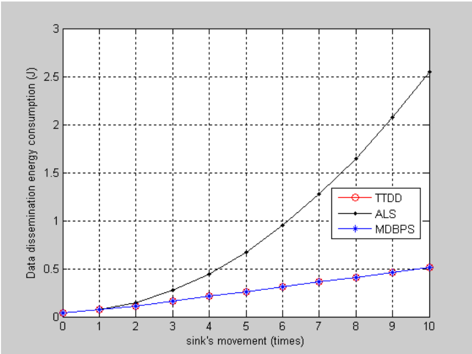

Figure 8. Total energy consumption for data dissemination

Fig. 9 illustrates the average data transmission delay for three methods. It is noticed that the average delay in the proposed MDBPS and TTDD protocol remains stable (the MDBPS has the lower delay time) while the average delay in the ALS protocol has increased drastically along the sink's movement. The reason is that in the ALS protocol the number of links for data dissemination will be accumulated as the sink's location changes continuously. Therefore the ALS is unsuitable for frequently moving sinks while the MDBPS is unaffected by sink's frequent movement.

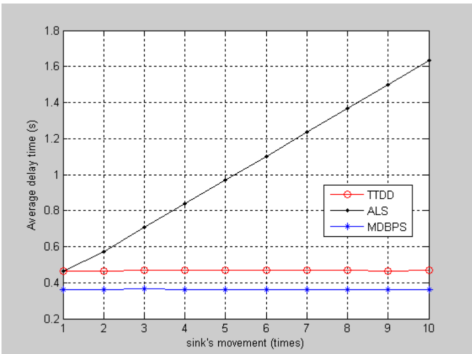

Figure 9. Average delay of the sink receiving data

Synthesizing the index of the energy consumption for location update and data dissemination as well as the delay time, the MDBPS method is proved to have better performance than the TTDD and ALS protocol. In addition, the MDBPS method utilizes extra signaling including the mobile sink's rough movement direction, average speed and initial moment to dynamically build the initial path from the source node to the sink, which is practical and simple without much overhead compared with the TTDD and ALS protocol.

V. CONCLUSIONS

In this paper, we describe the system framework of the convergence of the WSNs and MCNs and propose the movement direction based path selection method to solve the problem due to the sink's mobility in WSN. The simulation result reveals that the MDBPS method outperforms the ALS and the TTDD protocol in terms of total energy consumption for the routine updating and data transmission. So does the average delay. However, the path between the source agent and the sink agent is fixed according to the pre-defined principle, which might be not the most robust for the situation of the nodes damage and data collision etc. In addition, the MDBPS method is more suitable for non-rapid change of the movement direction of the mobile sink. In the future, most robust multiple potential paths between any two agent nodes could be further studied and the rapid change of the movement direction can be further discussed. Also the path selection method for multiple sources and multiple sinks could be further optimized under the assistance of the cellular network.

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