論文の内容の要旨

論文題目　A Study on Controlled Mobility in Disruption Tolerant Sensor Networks
（分断耐性センサネットワークにおけるモビリティ制御に関する研究）

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Recent advances in wireless technology, Micro-Electro-Mechanical System (MEMS) technology and low power microprocessors have enabled a new generation of large-scale Wireless Sensor Networks (WSNs). WSNs promise advantage in wide range of applications such as planetary explosion, ocean monitoring, wildlife habitat monitoring, detecting forest fires and floods, patient monitoring and vehicular or pedestrian traffic monitoring. In WSNs, generally, a large number of sensor nodes are deployed in the remote terrain. These nodes coordinate to establish a communication network, monitor specified tasks, and report sensed data periodically or spontaneously to the sink node. In massive-scale WSNs, a wireless communication range of the sensor node is not long enough to transfer the sensor data directly to the sink node, hence traditional approach for data collection in WSNs involves multi-hop wireless communication among the sensor nodes. However the multi-hop wireless communication may not always be possible due to network partitioning. The network partitioning may be easily occurred when the sensor nodes are deployed sparsely in the target area or when the existing sensor nodes are out of order by running out their butteries or some other software/hardware failures. One solution to tackle this issue is a use of redundant sensor nodes. However it is required massive number of sensor nodes for monitoring a large area such as planet, forest and ocean. Another solution is a use of mobility. If the sensor nodes have availability of movement, they can carry the sensor data to the sink node as well as construct a wireless communication path. We call such the sensor network, which is designed as disruption tolerant, Disruption Tolerant Sensor Networks (DTSNs).

Traditional works of utilizing mobility in DTSNs is mainly focused on mobility of sink node, where the sink node moves predetermined route to collect the sensor data from the static or mobile sensor node. In such the works, the network performance heavily depends on the behavior of mobile sink. For example, if the mobile sink is out of order, all the sensor data whose destination is this mobile sink are dropped. On the other hand, the conventional works focusing on mobility of sensor node is mainly exploiting there random or predictable mobility, i.e., sensors attached to animals and humans. Utilizing random mobility and predictable mobility for sensor nodes is able to make the network scalable compared to utilizing a controlled mobility for sink node. However, on the other hand, random and predictable mobility

sometimes generate huge delay, which causes data loss due to buffer overflow. Therefore, in this dissertation, we study and exploit the controlled mobility for sensor nodes to improve network performance in terms of data reachability, scalability and energy efficiency. Availability of controlled mobility for sensor node is currently growing; especially the emerging technology of multiple cooperated robots and embedded sensing devices brings us the use of mobile sensor robot for exploration in the large area such as the Moon, Mars and oceans. Hence the basic study of exploiting controlled mobility for sensor node is feasible to bring an emerging paradigm to the sensor network in the not-too-distant future.

Utilizing the controlled mobility, mobile node can move toward a wireless communication area that is covered by the destination node of data, instruct nearby node to move to a specific location or collaborate with other nodes to transfer data. In DTSNs, how to move and collaborate to minimize energy consumption for physical movement is a key problem, since the mobile node generally consumes much more energy than wireless communications in a unit time, and in sparse networks, mobile node moves for a long duration to carry the sensor data compared to duration of using wireless communication. To reduce the moving distance of mobile node, we can utilize store-carry-and-forward model, where the existing nodes relay the data from source to sink in one or more hops. Utilizing store-carry-and-forward model, the mobile node reduces the moving distance for wireless communication distance whose maximum value is the wireless communication range of wireless interface. This model is also beneficial in perspective of scalability because decisions of relaying can be made locally. However with decreasing the number of mobile node, the number of relaying from source node to sink per one bundle of sensor data is also decreasing. To overcome the issue, in this dissertation, we introduce an idea of concentrating the mobile nodes on a pre-determined path, in which sets of mobile nodes, called relay nodes, facilitate the connectivity to the sink node. Another crucial and challenging problem in DTSNs is the requirements of long-term communication, such as transmissions of continuous video from a specific hot spot. This is because that the mobile node has the difficulties on both storage and energy constrains. To overcome the above issues, in this dissertation, we introduce two significant approaches: sink-side approach and peer-side approach.

In the sink-side approach, we construct a single or multiple path(s) for relay nodes from the sink node, where the data is relayed hop by hop to the sink, so that the mobile node which is other than the relay node can reduce the distance of movement by forwarding the sensor data to the relay node which is on the constructed path. In the sink-side approach, we study the impact of single and multiple paths for the relay nodes. In our study, we observed that increasing the number of relaying nodes enlarges the affected area of reducing the moving distance for the mobile nodes which are other than relay node. However, if there is a constraint on the available number of relay nodes, increasing the number of relay nodes per path decreases the total number of path, and hence, the affected area of reducing the moving distance declines by a certain degree. Therefore, in this dissertation, we propose an algorithm to determine the optimal length and the number of paths to minimize the average moving distance of all the mobile nodes in the network to reduce the energy consumption. We also propose an algorithm to determine an optimal route for mobile node to the nearby constructed path. Our simulation result shows that optimizing the total number of paths reduces significant amount of energy for movement, when the sensor data is small size compared to the storage size of mobile node and generated intermittently.

For the continuous and massive-sized data from the hot spot, we need to take care about the storage overflow at the source node as well as the energy efficiency. Therefore, in the peer-side approach, we construct a direct path from the mobile node which is a source of the continuous and massive-sized sensor data to the sink node, on which the relay nodes may do round trip to transfer the sensor data. We also propose the algorithm for determining an optimal scheduling of relay nodes to meet the deadline of storage overflow at the source node. In the peer-side approach, we also propose an algorithm of local and temporal collaboration between nearby paths for relay nodes, where we partially combine and share the paths, so that the average moving distance per bundle can be reduced. In the algorithm, we construct an optimal tree within the nearby paths, which is base on the known algorithm for constructing the Euclidean Steiner Minimum Tree. Since the each path is temporal and has own duration, the tree-shaped combined path should be tolerant to dynamic change of its topology. Hence, we also propose the algorithm to handle the dynamic removal/addition of path(s) from/to the combined tree. The algorithm does not need to re-construct a whole tree configure the small part of the tree for the remaining/new path(s) so that we can reduce the overhead of re-constructing the whole tree. The simulation result shows that using tree-shaped combined paths we can reduce the energy consumption for movement compared to the single path based approach.

In this dissertation, to study the impact and evaluate our two approaches; sink-side approach and peer-side approach, we conduct the simulations and discuss the result. From the result, we can observe that, for non-continuous sensor data, the sink-side approach is better than the peer-side approach, and for continuous sensor data, the peer side approach is better than the sink-side approach in terms of energy efficiency and reachability of sensor data.