An Energy-Efficient Sensor Routing with low latency, scalability for Smart Home Networks

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Abstract

With advances in processor and wireless communication technologies, sensor networks will be used everywhere in the future life. Home networks are one of the good environments that sensor networks will be deployed. In sensor networks, many sensor devices detect various physical data and send them to the base station. In this paper, we present a sensor routing scheme, EESR (Energy-Efficient Sensor Routing) that provides energy-efficient data delivery from sensors to the base station. The proposed scheme divides the area into sectors and locates a manager node to each sector. The manager node receives collected data from sensor devices in its corresponding sector and then transfers the data to the base station through the shortest path of the 2-dimensional (x, y) coordinates. In this process, we use relative direction based routing in the 2-dimensional (x, y) coordinates in wireless sensor networks. Via simulation, we show that the proposed scheme achieve significant energy savings and outperform idealized transitional schemes (e.g., broadcasting, directed diffusion, clustering) under the investigated scenarios.

1. Introduction

In the emerging ubiquitous home, sensors will be placed everywhere in the house and measure various physical data such as temperature, humidity, motion, and light to provide information to the HVAC (Heating, Ventilating, and Air Conditioning) controlling system. For example, the HVAC controlling system turns on the ventilator when the air is foul and controls the heating system according to the weather and the existence of people in the house.

To realize these smart home networks, many sensor devices distributed in the house should detect events and send them directly to the base station through the wireless channel. Because the sensor devices do not have sufficient computational ability and battery power, an energy-efficient sensor routing scheme with low latency, scalability is critical to send information to the base station.

In the conventional sensor routing scheme, when each sensor node detects an event, it broadcasts the event to all sensor nodes within 1-hop range. All the sensor nodes within 1-hop, then, repeatedly broadcast the message to the next nodes. These processes are recursively performed until the event reaches the base station. This conventional scheme could lead to excessive drain of limited battery power and increase collisions in wireless transmission.

In this paper, we present a novel energy-efficient sensor routing scheme in wireless sensor networks, namely EESR (Energy-Efficient Sensor Routing). This scheme divides the area into sectors and locates a manager node to each sector. The manager node receives collected data from sensor devices in its corresponding sector and then transfers the data to the base station through the shortest path of the 2-dimensional (x, y) coordinates. In this process, we use relative direction based routing in the 2-dimensional (x, y) coordinates. We show that the proposed scheme provides energy-efficient data delivery to the base station with low latency, scalability.

The rest of this paper is organized as follows. Section 2 gives an overview of related works and the problems of the techniques. Section 3 presents the system model for the proposed scheme. In section 4, we present an energy-efficient sensor routing with low latency, scalability. Analysis and performance evaluations are described in section 5. Section 6 concludes this paper and points out some future research directions.

2. Related works

2.1. Directed Diffusion

Intanagonwiwat et al. proposed a scalable and robust communication paradigm, directed diffusion, for sensor networks [4]. They introduced the paradigm of directed diffusion in which all communication is for named data. Data generated by sensor nodes are named by attribute-value pairs. A node requests data by sending interests for named data. Data matching the interest is then drawn down towards that node. Intermediate nodes can cache, or transform data, and may direct interests based on previously cached data. All nodes in a directed diffusion-based network are application-aware. This enables diffusion to achieve energy savings by selecting empirically good paths and by caching and processing data in-network. However, sensor nodes should perform the complicated computations to generate attribute-value pair for named data and find good paths and cache and process data.

2.2. Data Dissemination Model Based on Grid Structure

Ye et al. suggested a data dissemination model based on the grid structure approach [5]. The approach provides scalable and efficient data delivery to multiple mobile sinks. Each data source in the data dissemination model proactively builds a grid structure and it enables mobile sinks to continuously receive data on the move by flooding queries within a local cell only. With a grid structure for each data source, queries from multiple mobile sinks are confined within their local cells only. This avoids excessive energy consumption and network overload from global flooding by multiple sinks. However, each data sources have overhead to exactly compute their location using unique geographical coordinates and proactively build a grid structure.

2.3. Clustering schemes

(Low Energy Adaptive Clustering Hierarchy) is designed for sensor networks where an end-user wants to remotely monitor the environment [6]. In such a situation, the data from the individual nodes must be sent to a central base station, often located far from the sensor network, through which the end-user can access the data.

Conventional network protocols, such as direct transmission, minimum transmission energy, multi-hop routing, and clustering all have drawbacks that don't allow them to achieve all the desirable properties. LEACH includes distributed cluster formation, local processing to reduce global communication, and randomized rotation of the cluster-heads. Together, these features allow LEACH to achieve the desired properties. However, because each sensor nodes can deliver the event only to the cluster-heads of randomized rotation, it makes the overhead to find the cluster head as well as cluster formation every time

3. An overview of the proposed system

Our system model consists of a gateway, a base station, several manager nodes, and a number of sensor nodes [7]. The gateway delivers commands received from a manager or out of the area to the base station and controls messages received from the base station. It can be located in any place of the area. The base station is a sensor node that has more computational ability and memory than general sensor nodes. It receives commands from the gateway and sends queries to sensor nodes. It also collects data from sensor nodes and delivers control messages to the gateway. The base station is located at the coordinate center of the area. Manager nodes and sensor nodes have ability to collect physical data and deliver the data to other nodes within 1-hop distance. Manager nodes are located in some predetermined position while other sensor nodes are randomly distributed in the area. In our scheme, the area of the application place is divided into four quadrants, namely (+ +), (+ -), (- -), and (- +), based on the 2-dimensional (x, y) coordinates as shown in Figure 1.

Each quadrant is then divided into sectors according to the distance from the base station. The number of sectors in each quadrant is determined by the minimum hops required to deliver a message from the base station to the farthest position in the quadrant. For example, each quadrant in Figure 1 has three sectors because any place in the application can be communicated within 3-hops from the base station. Each sector has one manager node in the center of the diagonal line of the quadrant. Note that the distance between adjacent two manager nodes is 1-hop.

The base station gives unique sector ID to each sector using directional antenna technology [8]. The sector ID is determined by the quadrant name and the distance from the base station. For example, in 1-hop distance from the base station, there are four sectors, namely, (+1+1) sector, (+1-1) sector, (-1-1) sector, and (-1+1) sector. Each sector has its corresponding manager node. Table I shows the quadrant names, sector IDs, and manger node names for the example given in Figure 1. Each sensor nodes make the EESR table including the relative direction information from base station, SectorIDs, by transmitting hello message within 1-hop neighbors.

4. EESR : Energy-Efficient Sensor Routing

Figure 2 shows the procedure of the energy-efficient with low latency, scalability. First of all, each sensor nodes receive the relative direction information, SectorID, from base station as soon as they are deployed and make the EESR table.

When a sensor node firstly detects an event, it investigates the sector IDs of all neighbor nodes within 1-hop in the EESR table to select the next node that will deliver the event. The following scenario shows the selection procedure of the next node shown in the red box of the Figure 2.

. If there is a manager node within 1-hop distance, that node is selected as the next node to deliver the event.

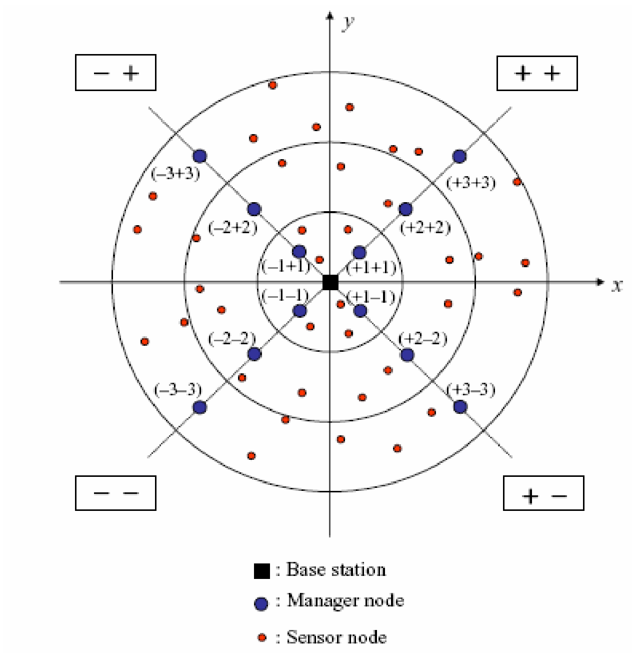

Figure 1. The locations of the base station, manager nodes, and sensor nodes based on the relative direction in the 2-dimensional (x, y) coordinates

TABLE I QUADRANT NAMES, SECTORID, AND MANAGER NODE NAMES

Distance from the base station	Quadrant name	SectorID	Manager Node name
1 hop	(+ +)	(+1 +1)sector	+1 +1M.N
	(+ −)	(+1 −1)sector	+1−1M.N
	(− +)	(−1−1)sector	−1−1M.N
	(−−)	(−1 +1)sector	−1+1M.N
2 hop	(+ +)	(+2 +2)sector	+2 +2M.N
	(+ −)	(+2 −2)sector	+2−2M.N
	(− +)	(−2−2)sector	−2 −2M.N
	(−−)	(−2 +2)sector	−2 +2M.N
3 hop	(+ +)	(+3 +3)sector	+3 +3M.N
	(+ −)	(+3 −3)sector	+3−3M.N
	(− +)	(−3−3)sector	−3 −3M.N
	(−−)	(−3 +3)sector	−3 +3M.N

. Otherwise, if nodes in the same sector exist within 1-hop distance, one of them is randomly selected as the next node.

. Otherwise, a neighbor node with the smallest sector number is selected as the next node because it is closest to the base station. If more than one node have the same smallest sector number, nodes in the same quadrant are preferred to prevent the event from going far to the other region.

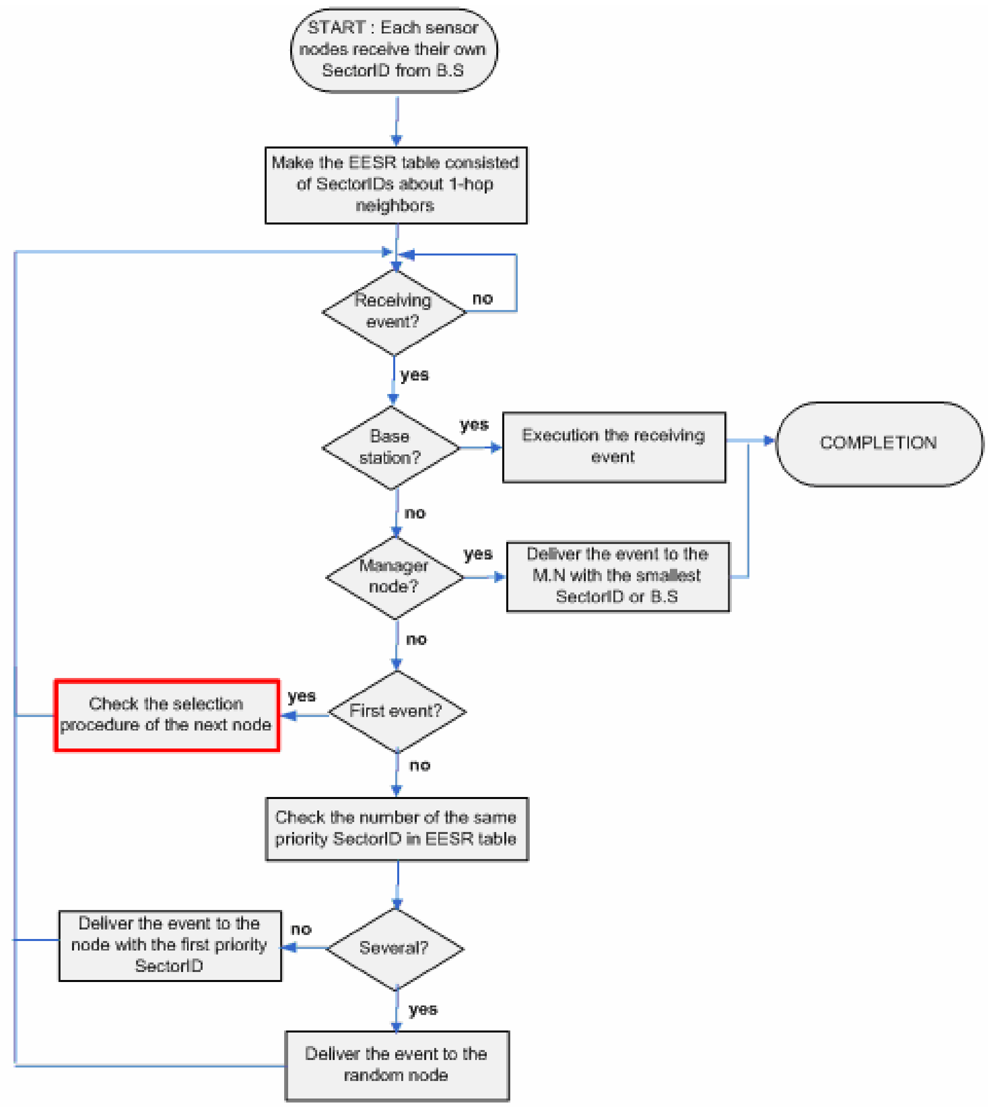

Figure 2. The procedure of the EESR scheme

After the event node selects one of the neighbors within 1- hop distance, it sends the event only to the selected sensor node. The selected node, then, performs the same selection procedure among neighbors within 1-hop distance, and sends the event only to the selected neighbor again. This procedure is repeated until the event arrives at the base station shown in Figure 2. This is different from the conventional routing scheme in which the event is broadcasted to all the other neighbor nodes globally until the event reaches the base station. Hence, it could lead to excessive energy consumption and network overhead. In our scheme, once a manager node is selected as the next node, the event can be delivered to the base station directly through the manger-to-manager transmission. In some cases, our scheme makes a detour because nodes in the same sector are randomly selected. However, this is the reason that every sensor nodes had better use their energy equally because the static path to base station decreases the life time of the whole network. For example, there can be different scenarios even for delivering the same event in Figure 3. This detour does not continue when a manager node is discovered. Also we use the max hop for preventing loop in worst case.

After receiving the first event, the EESR table of each sensor nodes is sorted to the result of the selection procedure of the next node according to the priority of the Sector ID. This makes all sensor nodes which have experienced to send the event easily find the next node for delivering the event. Therefore, from secondarily, each sensor nodes check the next sensor node having the SectorID of the highest priority in the EESR table when they receive the event. At that time, if sensor node checks the several SectorIDs of the same priority in the EESR table, it randomly selects one of them shown Figure4 (a). Otherwise, it sends the event only to the selected sensor node shown Figure4 (b), (c). Figure4 (b) shows the case that a neighbor node with other sector of different direction is selected as the next node because it only exists at that time. Figure4 (c) shows the case that a neighbor node with the smallest sector number is selected as the next node because it is closest to the base station. This delivery process is continued until the base station is found. During this process, once a manager node is found in route to the base station, the event is delivered to the base station through the manager-to-manager transmission shown in Figure 4(d). Because manager nodes deliver the data to the base station through the predefined shortest path of the 2-dimensional (x, y) coordinates, total number of broadcasting and energy consumption is reduced significantly as shown the experimental results part.

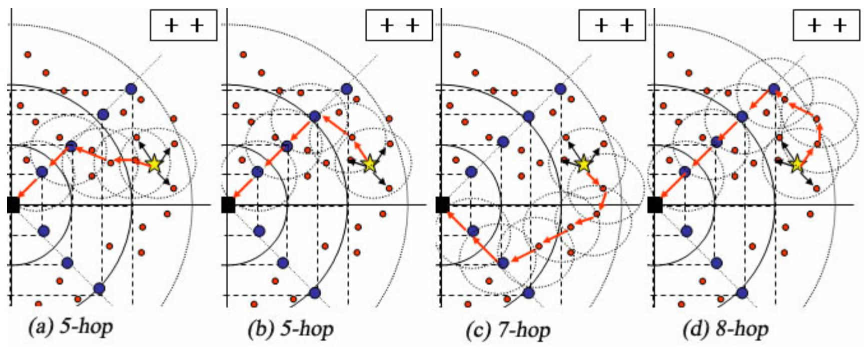

Figure 3. Different scenarios for delivering the same event

5. Experimental results

To evaluate the effectiveness of our scheme, we performed simulations with NS-2 simulator under various parameters. The parameters include radius from base station and number of ranges, sensor node's range and number according to the suitable network size and application. Also max node hop is needed for preventing loop. In each of our experiments, we study two different sensor fields, 200m by 200m and 400m by 400m, ranging from 50 to 250 nodes in increments of 50 nodes. Each node has a radio range of 40m. The base station is located in the center of the sensor field and manager nodes are located in pre-defined places. Other sensor nodes are randomly distributed using the random function of the NS-2 simulator.

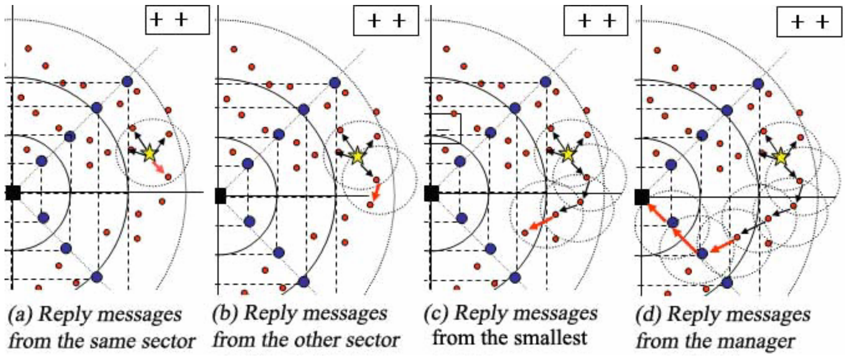

Figure 4. The example of the EESR using the selection procedure of next node

We choose three metrics to analyze the performance of the EESR scheme and compare it to other schemes (e.g., broadcasting, directed diffusion, clustering) under the investigated scenarios: energy evaluation such as total energy consumption, average energy consumption per node, and average delay time and packet delivery success ratio in case of the sparse network and the dense network. Total energy consumption measures the summation both the total energy for really delivering the event to the next node and the overhead for overhearing the event. Average energy consumption measures the ratio of total energy per node in the network. This metrics computes the average work done by a node in delivering the event to the base station and it also indicates the overall lifetime of sensor nodes. Average delay measures the packet delivering time from each sensor nodes to base station via manager nodes. Packet delivery success ratio is the ratio of the number of events received to the number originally sent.

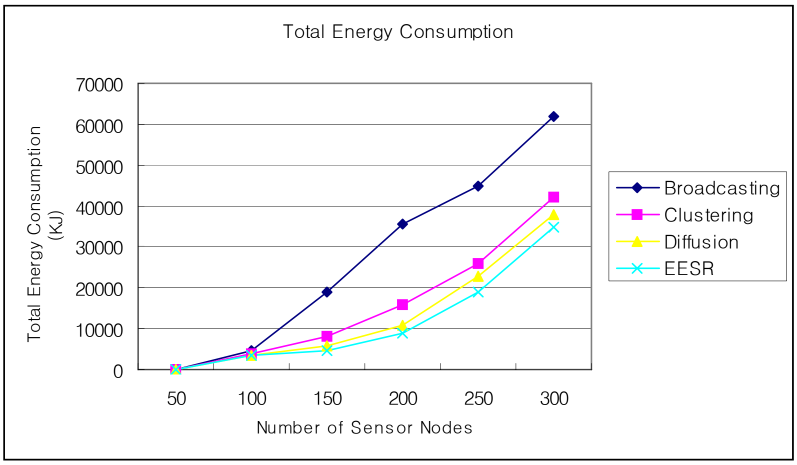

Figure 5. Total energy consumption

Our first experiment compares the total energy consumption of the EESR scheme to the broadcasting, directed diffusion, clustering. Figure 5 shows the total energy consumption of the four schemes as the number of sensor nodes. As can be seen from the figure, EESR shows consistently better performance than other conventional routing schemes. Specifically, the performance gap between EESR and conventional broadcasting becomes wider as the number of sensor nodes increases, which implies that EESR is more scalable than conventional broadcasting.

Figure 6 shows the average energy consumption per node as the number of sensor nodes increases. When average energy consumption per node is considered in each routing scheme, each node considers the number of sending event and receiving event within 1 hop neighbors. In broadcasting, each node sends the event to 1-hop neighbors and receives the event within 1-hop neighbors. And in cluster scheme, each node delivers the event until it finds the cluster head every time. And in diffusion, once each node detects a matching event wanted by base station, it sends exploratory events, possibly along multiple paths, towards the base station. Whereas in EESR, each node makes the EESR table including SectorIDs, by transmitting hello message within 1-hop neighbors only once. And when each node firstly detects an event, it investigates the sector IDs of all neighbor nodes within 1-hop in the EESR table to select the next node that will deliver the event. Specially, in EESR, average energy consumption per each node shows better performance than other schemes. Because each node communicates using SectorID which is small size than event itself and manager nodes exactly deliver the data to the base station through the predefined shortest path of the 2-dimensional (x, y) coordinates. The more sensor nodes increases, the more probability of finding the manager node and the node of the smallest SectorID increases, which implies that EESR is more scalable than conventional broadcasting.

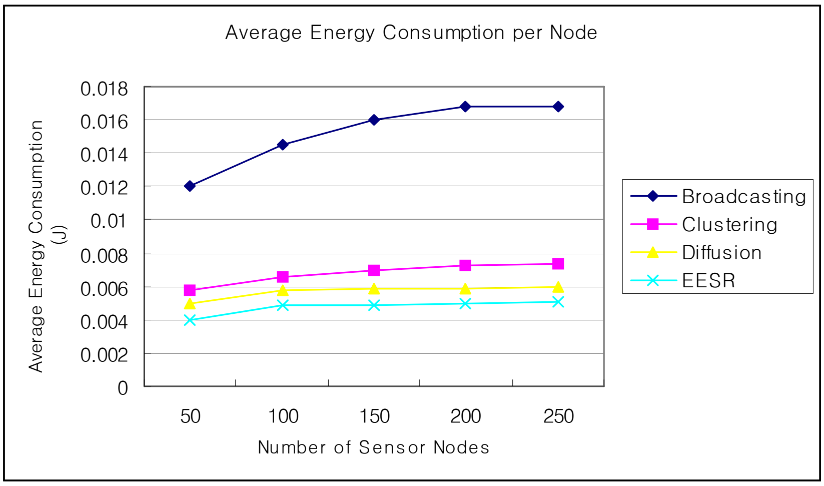

Figure 6. The average energy consumption per node

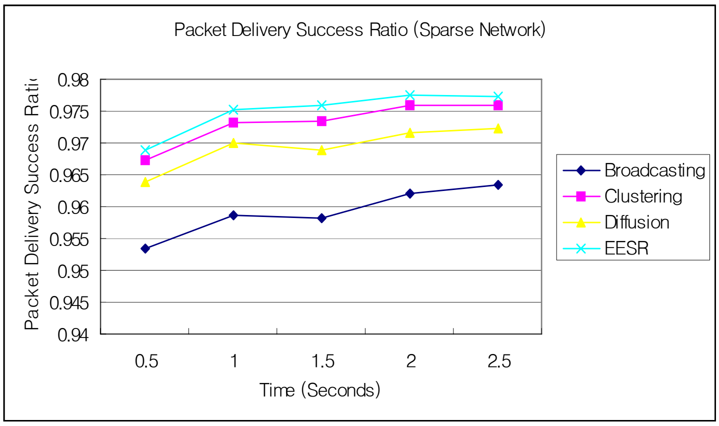

Figure 7. The average delay time

Figure 7 shows that the average delay time observed as a function of the number of sensor nodes. EESR is less delay time than other schemes although it sometimes makes a detour. This reason is that manager node of each sector solves this problem.

Figure 8 and Figure 9 show that the EESR scheme performs the better packet delivery success ratio than other schemes when the network specially is dense, which implies that EESR is more scalable than other schemes. In sparse network of our experiments, we experiment the sensor fields, 400m by 400m, and the number of sensor node, 50. In case of dense network, we consider the sensor fields, 400m by 400m, and the number of sensor node, 200. In each our experiment, each node has a radio range of 40m. The base station is located in the center of the sensor field and manager nodes are located in pre-defined places. Other sensor nodes are randomly distributed using the random function of the NS-2 simulator.

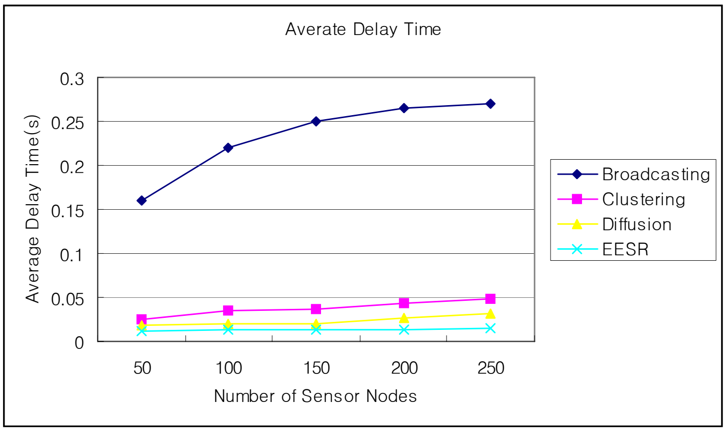

Figure 8. Packet delivery success ratio (Sparse Network)

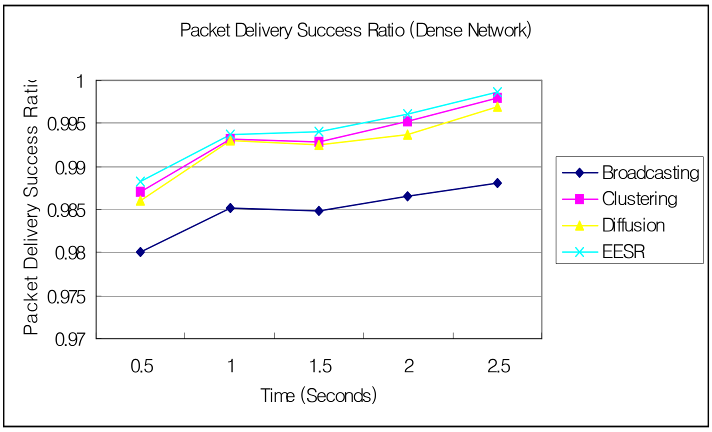

Figure 9. Packet delivery success ratio (Dense Network)

6. Conclusion

In this paper, we presented a novel energy-efficient sensor routing scheme with low latency, scalability for Smart Home Networks, namely EESR (Energy-Efficient Sensor Routing). EESR provides energy-efficient routing from sensor nodes to the base station using relative direction scheme. EESR divides the application area into sectors and locates a manager node to each sector. The manager node delivers sensed data to the base station efficiently through the shortest path of the 2-dimensional (x, y) coordinates. Performance results show that EESR reduces energy consumption significantly and performs well in terms of low latency and scalability, when compared to previous works.

7. Acknowledgement

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