This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2009 proceedings.

Wireless Multihop Transmission with Buffering in Neighbor Sensor Nodes for Shorter Delay

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***Abstract*—In wireless multihop transmission of sensor data, in addition to avoidance of contentions and collisions of wireless signals, available capacity of communication buffers in sensor nodes should be considered. If a communication buffer in a next-hop wireless sensor node is filled, it is impossible for a wireless sensor node to forward a message with sensor data to the next-hop one. Here, the sensor node stores the message to its communication buffer and waits for the buffer in the next-hop sensor node to have enough space. The buffered messages are required to be transmitted to a sink node as soon as possible. This paper proposes a method to store the messages not only into communication buffers in wireless sensor nodes along the multihop transmission route but also in wireless sensor nodes neighboring to the multihop transmission route. By applying this method, messages with sensor data are stored into communication buffers of wireless sensor nodes nearer to the sink node and shorter end-to-end transmission delay is required. We design a routing protocol and a message transmission protocol for implementation and evaluate time duration required to transmit all buffered messages to a destination sink node by comparing with the conventional multihop transmission protocol.**

I. Introduction

Wireless sensor networks are expected to be applied widely to acquisition of various environmental data. Especially for applying to a wide area, multihop data message transmission by multiple wireless sensor nodes are required for reduction of configuration and maintenance cost of the wireless sensor networks. For multihop data message transmission, a multihop transmission route from each sensor node to one of sink nodes connected to a wired network is required to be searched, detected and configured. However, the sensor nodes sometimes leave from the sensor network permanently due to failure and/or exhaustion of battery capacity and temporarily due to transition to a sleeping mode for reduction of battery consumption. In addition, the sensor nodes sometimes change their locations autonomously and/or heteronomously. Hence, dedicated routing protocols and data message transmission protocols are required to be designed based on ad-hoc routing protocols for mobile ad-hoc networks (MANTEs) [6]. For supporting sensor networks carrying data messages from sensor nodes detecting occurrences of events in the observation areas, it is feasible to adopt an on-demand routing protocol such as AODV [7], DSR [3] and TORA [5] for reduction of total communication overhead.

For such sensor network, it is required for sensor data messages to be carried with shorter transmission delay from a source sensor node to a destination sink node. Until now, various sensor data transmission protocols have been proposed for supporting repeated and continuous transmission of (almost) the same amount of sensor data, i.e. CBR (constant bit rate) traffic is required to be supported. However, in the event-driven sensor data transmission, amount of sensor data required to be transmitted is time-variant, i.e. VBR (variable bit rate) traffic is required to be supported. Since only a limited amount of message buffer is equipped in each sensor node, the message buffers in intermediate sensor nodes along a multihop transmission route may overflow due to congested event-driven sensor data messages. In order for avoidance of loss of sensor data messages, an intermediate sensor node suspends forwarding sensor data messages until enough amount of message buffer in its next-hop sensor node becomes available. However, the suspension causes longer end-to-end transmission delay. Hence, a method for transmission of such sensor data buffered in intermediate sensor nodes with shorter transmission delay is required. This paper proposes a novel sensor data transmission protocol in which sensor data messages under transmission are buffered in intermediate sensor nodes and their 1-hop neighbor sensor nodes as nearer as possible to the destination sink node for achieving shorter end-to-end transmission delay. In addition, an extended routing protocol based on AODV-BR [4] is also designed and performance of the proposed method is evaluated in a preliminarily simulation experiment.

II. Sensor Networks and Buffer Overflow

A. Sensor Networks

A wireless sensor network consists of sensor nodes with wireless communication devices and sink nodes connected to a wired network. Sensor data achieved in sensor nodes are transmitted to one of the sink nodes. Required electric power for sensing data acquisition and wireless signal transmission is provided by an equipped battery in each sensor node. Due to the limited battery capacity, it is impossible for all the sensor nodes to transmit sensor data messages directly to one of the sink nodes. Hence, the sensor data messages are transmitted to one of the sink nodes with help of other sensor nodes, i.e. by wireless multihop transmission of the sensor data messages. The sensor data messages are transmitted along a multihop transmission route $R = ||S_0 \dots S_n\rangle\rangle$ from each source sensor node S_s ($= S_0$) to a destination sink node S_d ($= S_n$) through intermediate sensor nodes S_i ($0 \leq i \leq n$). Each intermediate sensor node S_i receives sensor data messages from a previous-hop sensor node S_{i-1} and forwards them to a next-hop sensor node S_{i+1}. Here, S_i consumes electric power in the battery only for transmission of sensor data messages to S_{i+1} nearer than S_d.

In order to detect a multihop sensor data transmission route R, various ad-hoc routing protocols have been developed [6].

An ad-hoc network consists of mobile computers with wireless communication devices and an ad-hoc routing protocol is designed for support of various changes of network topology due to mobility of computers, failure of computers and battery exhaustion in computers. Especially for reduction of communication overhead required for repeated exchanges of network topology information, many on-demand (reactive) ad-hoc routing protocols in which a multihop transmission route R is searched, detected and configured just before transmission of data messages are researched and developed [3], [5], [7]. In a wireless sensor network, routing and sensor data message transmission protocols for wireless multihop transmission resilient to permanent changes of network topology due to failure of sensor nodes, battery exhaustion in sensor nodes and autonomous and heteronymous mobility of sensor nodes and to temporary changes of network topology due to transition to sleeping mode in sensor nodes for reduction of battery consumption.

There are 3 different types of sensor data transmission from a source sensor node to a destination sink node.

1) Reactive sensor data transmission issued by requests by client computers.
2) Scheduled sensor data transmission.
3) Event-driven sensor data transmission issued by a source sensor node detecting an occurrence of an event.

In type (1) sensor data transmission, if all wireless communication links are bidirectional (symmetric), a multihop sensor data transmission route R is detected by transmitting a request message issued by a client computer from a sink node S_d to a source sensor node S_s. Hence, a routing protocol is issued by S_d. In type (2) sensor data transmission, many or almost all sensor nodes transmit sensor data messages to a sink node. Hence, it is more reasonable to detect sensor data message transmission routes from the sensor nodes to the sink node by flooding of route detection control messages repeatedly issued by the sink node than to detect a route by each source sensor node [2]. However, the method can be applied to sensor networks only with bidirectional (symmetric) wireless communication links same as type (1) and only when sensor data message transmission is relatively more frequent than route detections whose frequency is depend on that of changes of network topology. Different from types (1) and (2), in type (3) sensor data transmission, sensor data message transmissions are initiated in a source sensor node and there are no or less repeated sensor data transmission requests. Hence, on-demand sensor node initiated route detection is feasible.

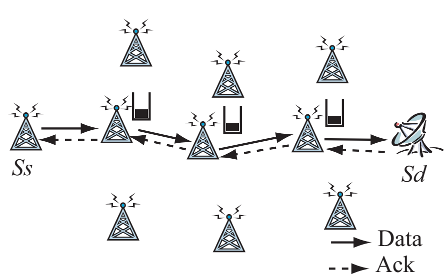


Fig. 1. Wireless Multihop Transmission of Sensor Data Messages without Buffer Overflow.

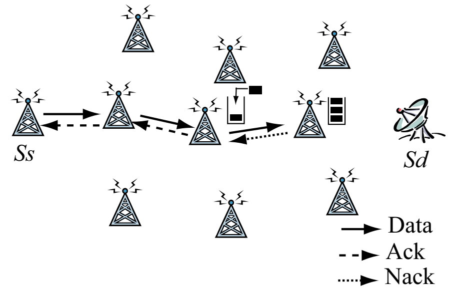


Fig. 2. Wireless Multihop Transmission of Sensor Data Messages with Buffer Overflow.

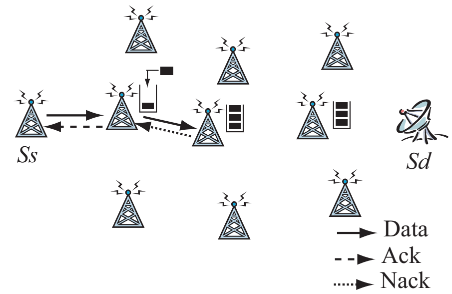


Fig. 3. A Sequence of Buffer Overflows along Multihop Transmission Route.

B. Buffer Overflow Problem

Due to requirements for miniaturization and low price of sensor nodes, not only limited battery capacity but also limited amount of memory used for buffer of sensor data achieved by a sensor devise or received by a wireless communication devise are equipped. In wireless multihop sensor data message transmission along a multihop transmission route $R = ||S_0 \ldots S_n\rangle\rangle$, if a message buffer in S_{i+1} is filled over a predetermined threshold amount, it is impossible for S_{i+1} to receive a sensor data message from S_i for avoidance of buffer overflow. In this case, S_i fails to transmit the sensor data message, stores it into a message buffer temporarily and re-transmits it after a certain interval. However, during the interval, the message buffer in S_i might be also filled with sensor data messages under multihop transmission and it becomes impossible for S_i to receive sensor data messages forwarded by S_{i-1}. Then, a sequence of message buffers in R overflow and end-to-end transmission delay along R gets longer. Such a congestion with a sequence of message buffer overflow tends to occur due to temporary increase of transmission requests of sensor data messages in a sensor network with event-driven sensor data transmissions. Especially, when multiple sensor nodes detect occurrences of events simultaneously, message buffers in sensor nodes around a sink node often overflow. In this paper, all wireless communication links between sensor nodes and between a sensor node and a sink node provide enough bandwidth for transmission of all sensor data messages. The above mentioned buffer overflow problem is caused by temporary congested transmission requests for sensor data messages and our proposed method in the next section solves temporary buffer overflows in a sequence of intermediate sensor nodes. That is, this paper does not provide a solution for permanent lack of bandwidth for transmitted sensor data messages. In a wireless sensor network with type (3) sensor data transmissions in the previous subsection, a large number of sensor data messages are transmitted only if an event is observed by a set of sensors and much less sensor data messages and/or control messages are transmitted otherwise; i.e. required bandwidth (bit-rate) are time-variant. Since it is impossible for each sensor node to be equipped enough message buffer for support of the maximum transmission request for sensor data messages due to miniaturization and low-price requirements, the temporary buffer overflow problem is inevitable. However, even in such congestions of sensor data messages, end-to-end transmission delay is required to be short and message loss ratio is required to be low as possible for correct execution of sensor network applications.

For wireless ad-hoc networks, routing and multihop data message transmission protocols for shorter end-to-end transmission delay have been researched and designed. In MARCH [8], an extended wireless LAN protocol for reduction of communication overhead caused by RTS/CTS control based on the fact that S_i surely transmits data messages received from S_{i-1} to S_{i+1} is designed for shorter end-to-end multihop data message transmission. However, this protocol is designed based on an assumption that a next-hop sensor node always receives forwarded sensor data messages when there are no collisions and contentions with sensor data transmissions of the other sensor node, i.e. there are no consideration about message buffer overflows. On the other hand in [1], a scheduled sensor data transmission method for shorter end-to-end transmission delay is proposed. Here, a closely synchronized clock is assumed to be shared among all sensor nodes and a sink node. In addition, since a sensor data message transmissions are scheduled by a sink node and the schdule information is broadcasted by the sink node, all sensor nodes are required to be in a wireless signal transmission range of the sink node. Here, the sensor data message transmissions are scheduled based only on occurrences of collisions and contentions among multiple sensor data message transmissions and availability of message buffers are out of consideration.

III. Neighbor Buffering

We suppose the case that in wireless multihop sensor data transmission along a wireless multihop transmission route $R = ||S_0 S_1 \dots S_n\rangle\rangle$ from a source sensor node S_s $(= S_0)$ to a destination sink node S_d $(= S_n)$ and the message buffers in k intermediate sensor nodes $\{S_{n-k}, \dots, S_{n-1}\}$ are filled by sensor data messages under transmission. In the conventional sensor data transmission in which sensor data messages are transmitted only along the message transmission route, i.e. only S_i in R are engaged in sensor data message transmission, it is possible for S_i to forward a sensor data message to its next-hop sensor node S_{i+1} only when there are enough amount of free message buffer in S_{i+1}. Figure 4 shows an example where $n = 6$ and $k = 6$.

In this paper, it is assumed that all sensor data messages are the same size and each sensor node has a message buffer for only 1 message for simplicity. Due to restrictions for transmission, e.g. requirement for message buffers in receipt sensor nodes and avoidance of collisions in multiple access to wireless media in a wireless LAN protocol, for transmission of the buffered 6 sensor data messages in Figure 4, 15 time units in Table I are required even in an ideal case

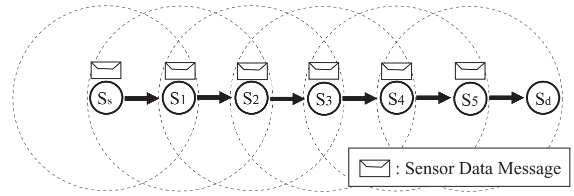


Fig. 4. Buffered Sensor Data Message along Message Transmission Route.

in a synchronous environment where any 1-hop sensor data message transmission requires 1 time unit.

TABLE I
Sensor Data Message Transmissions along Message Transmission Route.

1	$S_5 \to S_6$	9	$S_2 \to S_3$, $S_5 \to S_6$
2	$S_4 \to S_5$	10	$S_0 \to S_1$, $S_3 \to S_4$
3	$S_5 \to S_6$	11	$S_1 \to S_2$, $S_4 \to S_5$
4	$S_3 \to S_4$	12	$S_2 \to S_3$, $S_5 \to S_6$
5	$S_4 \to S_5$	13	$S_3 \to S_4$
6	$S_2 \to S_3$, $S_5 \to S_6$	14	$S_4 \to S_5$
7	$S_3 \to S_4$	15	$S_5 \to S_6$
8	$S_1 \to S_2$, $S_4 \to S_5$		

This paper proposes a novel method for achieving shorter end-to-end transmission delay even with such filled message buffers in intermediate sensor nodes. Here, such sensor data messages for which it is not impossible to be forwarded to a next-hop sensor node with filled message buffer are forwarded to one of neighbor sensor node with a free message buffer nearer to the destination sink node. That is, a sensor node S_i forwards a sensor data message not to its next-hop sensor node S_{i+1} along R with filled message buffer but to another sensor node S'_{i+1} with free message buffer neighboring to S_{i+1} and out of R. Now, the sensor data message is stored in a message buffer in S'_{i+1} nearer to S_n than S_i.

Here, S'_i is in wireless signal transmission ranges of both S_{i-1} and S_{i+1} $(0 \leq i \leq n)$. In case that each intermediate sensor node has/selects only 1 such a neighbor sensor node, the 6 sensor data messages in Figure 4 are stored into message buffers in S_3, S'_3, S_4, S'_4, S_5 and S'_5 as shown in Figure 5. If S'_{i+1} $(0 \leq i \leq n)$ is in a wireless signal transmission range of S_i and vice versa, only 12 time units as shown in Table II are required ideally for the 6 buffered sensor data messages to be transmitted to S_d. That is, 3 time unit shorter transmission delay than the conventional protocol is required.

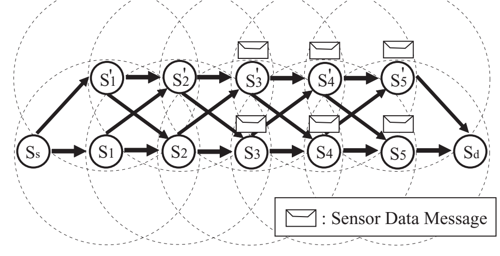


Fig. 5. Buffered Sensor Data Messages with 1 Neighbor Message Buffer.

Figure 6 shows the case that each intermediate sensor node S_i has 2 neighboring sensor nodes S_i^L and S_i^R as backup nodes

TABLE II
SENSOR DATA MESSAGE TRANSMISSIONS WITH 1 NEIGHBOR MESSAGE BUFFER.

1	$S_5 \to S_6$	7	$S'_5 \to S_6$
2	$S_4 \to S_5$	8	$S'_4 \to S_5$
3	$S_5 \to S_6$	9	$S_5 \to S_6$
4	$S_3 \to S_4$	10	$S'_3 \to S_4$
5	$S_4 \to S_5$	11	$S_4 \to S_5$
6	$S_5 \to S_6$	12	$S_5 \to S_6$

for temporarily storing sensor data messages into message buffers. Here, the 6 sensor data messages are stored in S_4, S_4^L, S_4^R, S_5, S_5^L and S_5^R and only 9 time units as shown in Table III are required ideally to be transmitted to S_d. That is, 6 time units shorter transmission delay than the conventional protocol is required.

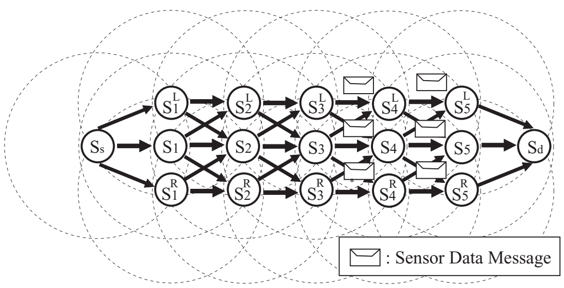


Fig. 6. Buffered Sensor Data Messages with 2 Neighbor Message Buffers.

TABLE III
SENSOR DATA MESSAGE TRANSMISSIONS WITH 2 NEIGHBOR MESSAGE BUFFERS.

1	$S_5 \to S_6$	6	$S_4 \to S_5$
2	$S_5^L \to S_6$	7	$S_5 \to S_6$
3	$S_5^R \to S_6$	8	$S_4^R \to S_5^R$
4	$S_4^L \to S_5^L$	9	$S_5^R \to S_6$
5	$S_5^L \to S_6$		

In order to realize the proposed sensor data transmission and buffering method with help of neighbor sensor nodes, novel routing and sensor data transmission protocols are required to be designed. In the routing protocol, not only a sensor data transmission route R from S_s to S_d is detected and configured but also backup sensor nodes S'_i of each S_i which are included in wireless signal transmission ranges of both S_{i-1} and S_{i+1} are detected and registered to a routing table in S_{i-1} as backup next-hop sensor nodes in case of filled message buffer in S_i. In the sensor data transmission protocol, S_{i+1} sends back a negative acknowledgment ($Nack$) message to S_i for a sensor data message if the message buffer in S_{i+1} is filled and S_i forwards the sensor data message to one of the backup next-hop sensor nodes S'_{i+1}.

IV. NEBUST PROTOCOL

As discussed in the previous section, this paper proposes the novel method for transmission of congested sensor data messages to a destination sink node with shorter end-to-end transmission delay. Here, neighbor sensor nodes of a multihop transmission route are engaged in transmission of sensor data messages only when sensor data messages are congested and some message buffers in sensor nodes overflow. NeBuST Protocols (Protocols for Neighbor Buffering for Congested Sensor Data Transmission) is designed in this section by which such sensor data messages are forwarded not to the original next-hop sensor node in the multihop transmission route but to one of the neighbor sensor nodes with enough message buffer nearer to the destination sink node. NeBuST consists of a routing protocol and a sensor data message transmission protocol.

NeBuST routing protocol is an extension of on-demand ad-hoc routing protocols in which flooding of a route request control message $Rreq$ is applied for detection of a multihop transmission route from a source sensor node S_s to a destination sink node S_d and unicast transmission of a route reply control message $Rrep$ is applied for notification of the detected multihop transmission route. In this paper, it is designed as an extension of AODV. AODV-BR is an extension of AODV for achieving resilient data message transmission even in case of route disconnection by using 1-hop route modification.

In AODV-BR, one of the neighbor sensor nodes satisfying the following conditions is selected and configured as a backup intermediate sensor node for route modification in case of route disconnection caused by a broken communication link between S_i and S_{i+1}:

[Backup Selection Conditions in AODV-BR]
A sensor node S satisfying the following 2 conditions can be selected as a backup sensor node of S_i in R:

- S is in a wireless signal transmission range of S_{i+1}.
- S is in a wireless signal transmission range of one of S_j where $0 \leq j \leq i$. □

In AODV-BR, keeping high connectivity is the most important for avoidance of unreachable data messages even in case of route disconnection, it is allowed to introduce S as an additional intermediate sensor node in R, i.e. an additional hop in R is acceptable. However, in NeBuST routing protocol, since the design objective is achievement of shorter end-to-end transmission delay, an additional hop is prohibited and the following conditions are applied:

[Backup Selection Conditions in NeBuST]
A sensor node S satisfying the following 2 conditions can be selected as a backup sensor node of S_i in R:

- S is in a wireless signal transmission range of S_{i+1}.
- S is in a wireless signal transmission range of S_{i-1}. □

In NeBuST routing protocol, a backup intermediate sensor node S'_i of S_i in R is detected and registered to a routing protocol in the previous hop sensor node S_{i-1} as a backup next-hop for multihop transmission to S_d. This is implemented by overhearing of unicasted $Rrep$ control messages same as in AODV-BR. A sensor node S overhears both $Rrep$ messages unicasted by S_{i+1} and S_{i-1} satisfies the above conditions for a backup sensor node S'_i of S_i in R. Now, S'_i registers S_{i+1} as a next-hop sensor node for message transmission to S_d and transmits a substitute route proposal control message $Rprop$ to S_{i-1} in order to notify S_{i-1} that S'_i is a backup next-hop sensor node of S_{i-1} for message transmission to S_d. On receipt of the $Rprop$ control message, S_{i-1} registers S'_i into a routing table as an additional next-hop sensor node for messages destined to S_d. It is possible for a backup sensor node S'_{i-1} of S_{i-1} to register S'_i in a routing table as a backup next-hop sensor node to S_d by overhearing the $Rprop$ control message unicasted from S'_i to S_{i-1}. Thus, even if it is impossible for S'_{i-1} to transmit sensor data messages to S_i due to overflow of message buffer in S_i, S'_{i-1} forwards the messages to S'_i if there is an available message buffer in S'_i.

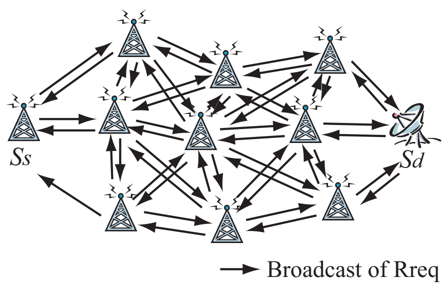


Fig. 7. Flooding of **Rreq** in NeBuST Routing Protocol.

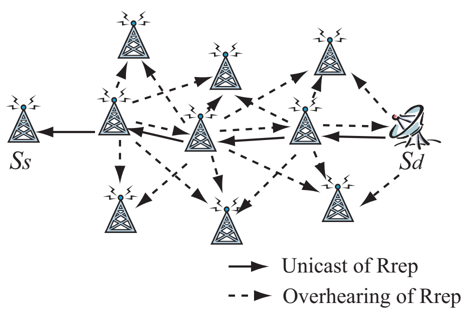


Fig. 8. Unicast and Overhearing of **Rrep** in NeBuST Routing Protocol.

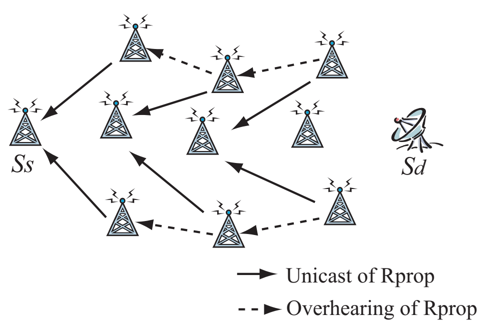
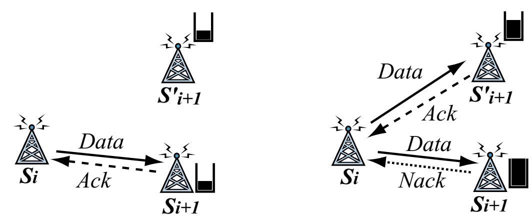


Fig. 9. Unicast and Overhearing of **Rprop** in NeBuST Routing Protocol.

According to NeBuST routing protocol, in the original ith-hop intermediate sensor node S_i and its backup sensor node S'_i, an entry with a next-hop S_{i+1} and a destination S_d is registered into a routing table and another entry with a next-hop S'_{i+1} and a destination S_d is registered into a substitute routing table. A number of entries in a substitute routing table depends on topology of a sensor network. Hence, a sensor node has no entry, only a single entry or multiple entries in a substitute routing table. On receipt of a sensor data message destined to S_d from the previous-hop sensor node S_{i-1} (or one of the backup previous-hop sensor nodes S'_{i-1}), S_i unicasts the received data message to the next-hop sensor node S_{i+1} according to a routing table. If there is an available message buffer for storing the data message in S_{i+1}, S_{i+1} sends back an acknowledgment message Ack to S_i and the 1-hop data message transmission completes. On the other hand, there is not an available message buffer for storing the data message in S_{i+1}, S_{i+1} sends back a negative acknowledgment message $Nack$ to S_i in order to inform S_i of an occurrence of buffer overflow in S_{i+1}. On receipt of the $Nack$ control message, S_i unicasts the sensor data message to one of the backup next-hop sensor node S'_{i+1} according to the substitute routing table. If S_i receives an Ack control message from S'_{i+1}, the 1-hop data message transmission completes. Otherwise, i.e. S_i receives a $Nack$ control message from S'_{i+1}, S_i unicasts the sensor data message to another backup next-hop sensor node according to the substitute routing table. In case that S_i receives $Nack$ control messages from all the candidate of the next-hop sensor nodes, S_i stores the sensor data message into the message buffer and suspends the transmission until one of the candidate next-hop sensor nodes has an available message buffer.



(a) Next-hop with Available (b) Next-hop with Filled Buffer

Fig. 10. Proposal 1-hop Transmission based on Status of Next-hop Message Buffer.

V. Performance Evaluation

This section evaluates performance of NeBuST protocols. In a sensor network with randomly located sensor nodes based on unique distribution randomness, required time for transmission of sensor data messages buffered during multihop transmission to a sink node is evaluated in simulation. A simulation field is a 500m 500m square and a wireless signal transmission range of all sensor nodes is a 100m radius circle. 100–300 sensor nodes and a sink node are randomly located and no nodes change their location during simulation. A message buffer for only 1 sensor data message is equipped to each sensor node. Figures 11, 12 and 13 show average required time for transmission of k ($k = 1, \dots, 6$) buffered sensor data messages to a sink node by NeBuST data message transmission protocol and multihop data message transmission protocol based on AODV with 100, 200 and 300 sensor nodes, respectively.

Even with more buffered sensor data messages, less increase of transmission time is required in NeBuST then in AODV and the required time by NeBuST is reduced in higher density environments. As shown in Figure 14, 47%, 68% and 72% shorter time is required by NeBuST then by AODV with 100, 200 and 300 sensor nodes, respectively. That is, reduction ratio of required time is higher in higher density environments and the reduction ratio is saturated at about 80%. Thus, NeBuST works better in high density wireless sensor networks.

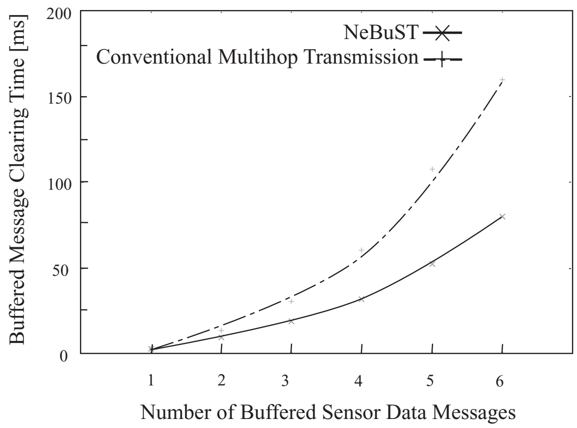


Fig. 11. Required Time for Clearing Buffered Sensor Data Messages (100 Sensor Nodes).

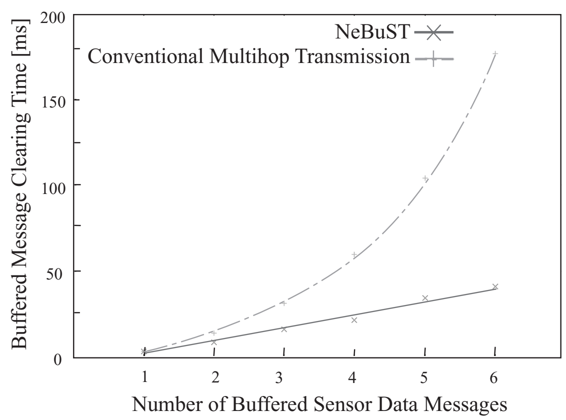


Fig. 12. Required Time for Clearing Buffered Sensor Data Messages (200 Sensor Nodes).

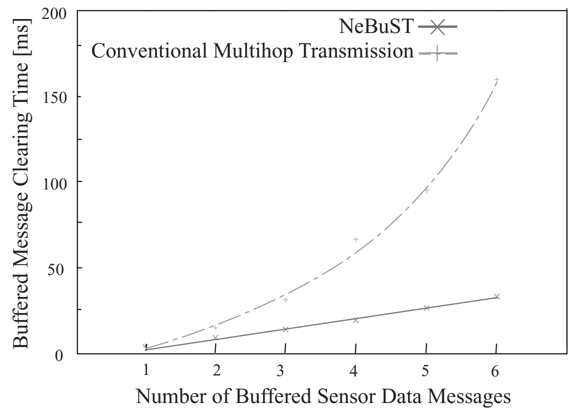


Fig. 13. Required Time for Clearing Buffered Sensor Data Messages (300 Sensor Nodes).

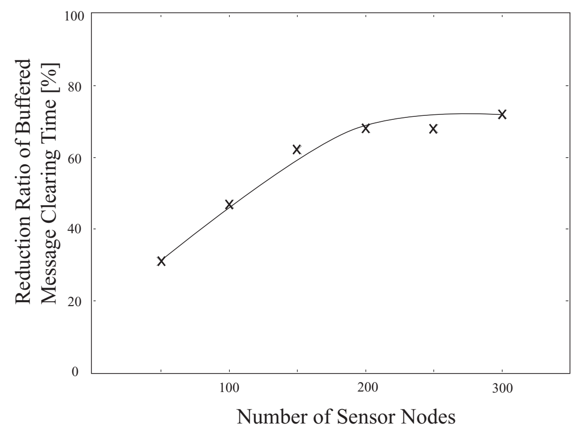


Fig. 14. Reduction Ratio of Buffered Message Clearing Time

VI. Concluding Remarks

This paper proposed a novel sensor data transmission method with considertation of limited sensor data message buffers in intermediate nodes along a wireless multihop transmission route from a source sensor node to a destination sink node. If the message buffer in an original next-hop sensor node is filled by other sensor data messages, an intermediate sensor node transmits sensor data messages to a backup next-hop sensor node neighboring to the original one. For the method, NeBuST routing and data message transmission protocols have been designed and their performance is evaluated in simulation by comparison with the conventional multihop data transmission protocol with AODV. The simulation results show that NeBuST requires shorter time to transmit buffered messages to a sink node, i.e. NeBuST is more resilient to temprary congestion of sensor data messages than the conventional protocols. In future work, we evaluate end-to-end transission delay of sensor data messages in simulation experiments.

References

[1] Akamine, R. Watanabe, T., "On a Scheduling Method for Reducing MAC Collision in Sensor Networks" IEICE Technical Report, Vol. 107, No. 293, pp. 63–67 (2007).

[2] Corson, M.S. and Ephremides, A., "A Distributed Routing Algorithm for-Mobile Wireless Networks," ACM Journal of Wireless Networks, Vol. 1, No. 1, pp. 61–81 (1995).

[3] David, B., David, A. and Hu, Y.C., "The Dynamic Source Routing Protocol," Internet Draft, draft-ietf-manet-dsr-10.txt (2005).

[4] Lee, S.J. and Gerla, M., "AODV-BR: Backup Routing in Ad hoc Networks," Proceedings of the IEEE Wireless Communications and Networking Conference, pp. 1311–1316 (2000).

[5] Park, V. and Corson, S., "Temporally-Ordered Routing Algorithm (TORA) Version 1 Functional Specification," Internet Draft, draft-ietf-manet-tora-spec-04.txt (2001).

[6] Perkins, C.E., "Ad-Hoc Networking," Addison-Wesley (2001).

[7] Perkins, C.E. and Royer, E.M., "Ad hoc On-Demand Distance Vector Routing," RFC 3561 (2003).

[8] Toh, C.K., Vassiliou, V., Cuichal, G. and Shih, C.H., "MARCH: A Medium Access Control Protocol for Multiple Wireless Ad Hoc Networks," Proceedings of the IEEE Military Communications Conference, pp. 512–516 (2000).

[9] "GloMoSim," http://pcl.cs.ucla.edu/projects/glomosim/ .

[10] "Local and Metropolitan Area Network Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," Standard IEEE 802.11 (1997).

[11] "Local and metropolitan area networks Specific requirements Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY)vSpecifications for Personal Area Networks (WPANs(tm))," Standard IEEE 802.15.1 (2002).

[12] "Local and metropolitan area networks specific requirements part 15.4: wireless medium access control (MAC) and physical layer (PHY) specifications for low-rate wireless personal area networks (LR-WPANs)," Standard IEEE 802.15.4 (2003).