An Energy-Efficient Reliable Transport for Wireless Sensor Networks

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Abstract. In a wireless sensor network, sensor devices are connected by unreliable radio channels. Thus, the reliable packet delivery is an important design challenge. The existing sensor-to-base reliable transport mechanism, however, depends on a centralized manager node, incurring large control overheads of synchronizing reporting frequencies. In this paper, we present a *decentralized* reliable transport (DRT) with two novel decentralized reliability control schemes. First, we propose an independent reporting scheme where each sensor node stochastically makes reporting decisions. Second, we describe a cooperative reporting scheme where every sensor node implicitly cooperates with its neighbors for the uniform reporting. In the reporting step, DRT uses a reliable MAC channel, which is specifically optimized for reducing the energy dissipation. Experimental results show that DRT satisfies the desired delivery rate reliably in a decentralized manner while it significantly reduces the energy consumption of the radio device and the communication time.[1]

1 Introduction

Nowadays, the computing paradigm is rapidly shifting from the desktop to the ubiquitous environments. As a wireless sensor network reflects the network environment of the ubiquitous computing, researches on a wireless sensor network are becoming increasingly active [1]. A wireless sensor network is organized with numerous tiny sensor devices, which collect various physical data such as temperature, light, sound, and movement in a cost-efficient manner. The sensor nodes, i.e. Mote [2] and Smart-Its [3], are interconnected by a harsh radio channel so as to build an ad-hoc communication path. This routing path is mainly used to transfer the sample data from sensor nodes to base nodes, which report the data to users. Due to the relative ease of construction, various practitioners are trying to use this sensor network for monitoring and collecting tasks. For example, computer administrators are monitoring the temperature and the power usage of their computer center, medical doctors are checking the vital data of their patients such as electrocardiogram, and the military soldiers are checking the sound of points of strategic importance to watch the behavior of their enemy.

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In fact, there exist mainly two challenges that should be addressed to practically use the wireless sensor networks in various social fields. One is the reliability problem. In this paper, we define the *reliability* as the ratio of the number of collected sample data to the number of interested sensor nodes. Since a radio device used in the sensor nodes has a high packet error rate of about 50% [4], the reliable data delivery is an important challenge, especially when the network dimension is large. The other is the energy consumption problem. As the sensor nodes are powered by their small batteries that usually cannot be recharged, the power saving is a paramount design objective in the wireless sensor networks. Hill and Culler *et al.* [5, 6] reported that a radio device forms about 20-60% of the total power consumption of a sensor node. Therefore, the radio device should be managed efficiently to lessen the power consumption.

One of the effective ways of improving the reliability is adopting a reliable transport protocol [1]. Recently two different reliable transports of RMST [7] and ESRT [8] were developed for the sensor networks. RMST employs ARQ [14] protocol in link layer and a selective NACK protocol in transport layer. Thus, it guarantees the complete end-to-end reliability from sensor nodes to base nodes. However, the sensor networks are often interested in reliable detection of the collective information provided by the numerous sensor nodes not in their individual reliable reports. Thus, the complete end-to-end reliable transports include RMST are not generally applicable in the sensor network regime.

In order to provide a reliable detection of events occupied in the sensor network, a centralized reliable transport, namely ESRT [8], was recently presented. In ESRT, a base node directly controls the reporting frequency of all sensor nodes, so that it ensures the desired partial reliability. Specifically, when the current measured reliability is lower than the desired, the base node aggressively adjusts the reporting frequency so as to reach the desired one as soon as possible. If the measured one is higher than the required, the base node conservatively reduces the reporting frequency so as to conserve the energy.

However, since ESRT frequently changes the reporting frequency of all sensor nodes using a multicast protocol, it incurs serious control overheads of the energy consumption and the network congestion. Even though when the base node uses a powerful radio device for controlling the reporting frequency, the powerful yet expensive base node can not efficiently deliver the control signal to all sensor nodes in the wireless sensor networks. For example, as the network diameter increases, the radio device becomes gradually expensive so as to provide the high radio signal power. Also when the physical network topology is complex, the base node cannot directly transfer the control signal to all sensor nodes even though the distance to the sensor nodes is shorter than the communication range of its radio device.

To overcome these technical obstacles, in this paper, we present an energy-efficient decentralized reliable transport (DRT) that does not require a powerful radio device. In DRT, the querying packet embeds the desired reliability value and is propagated to all sensor nodes placed in the routing path. Then, all sensor nodes use one of two decentralized reliability control schemes of an independent reporting and a cooperative reporting. In the independent reporting, each sensor node stochastically makes the reporting decision whether it will report the sample data or not. Next, in the cooperative reporting, each sensor node implicitly cooperates with its neighbor nodes for the uniform reporting. These two decentralized reliability control schemes assure the measured reliability as similar to the desired one because the sensor nodes use reliable channel in the delivery of their sample data. The reliable channel is specifically optimized for improving the delivery speed and reducing the energy dissipation.

To study the performance of DRT over the existing transports, we use a byte-level sensor network simulator, which has been specifically developed for this purpose. The simulation results show that DRT with the cooperative scheme always guarantees the desired reliability. The results also show that DRT reduces both the energy consumption of the radio device and the operation completion time significantly. Finally, we show that the cooperative reporting scheme distributes the reporting density more uniformly than the independent reporting scheme.

The rest of this paper is organized as follows. Section 2 summarizes the related work. Section 3 presents the overall organization of DRT as well as some specific working mechanisms. We describe the simulation methodology and the simulation results in Section 4. Finally, Section 5 concludes with a summary.

2 Related Work

In this section, we provide the performance of an unreliable protocol that uses a retransmission technique. Then, we summarize the existing reliable MAC- and transport-layer protocols in comparison with DRT.

The main characteristic of the wireless sensor networks is that they have a high packet error rate, and the error rate is liable to change depending on the physical state. Rubin [4] reported that a harsh radio channel used in the sensor networks has a high bit error rate (e) of about 0.5%. If a packet length (L) is twenty bytes, the average packet error rate (E_L) exceeds 55%. With an unreliable protocol, the successful packet delivery rate can be described as $(1-E_L)H$ where variable H means a number of hops. When a hop count is larger than or equal to four, the delivery rate is less than 10

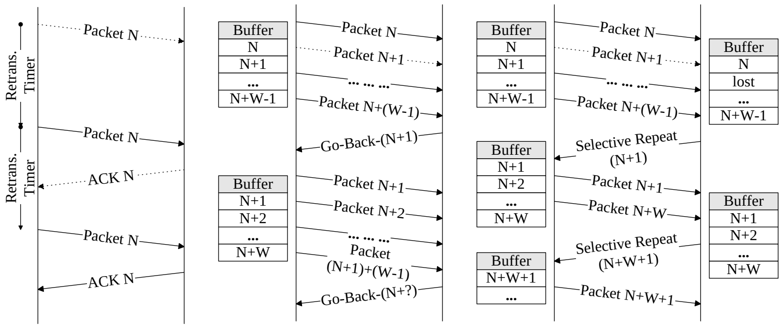
A packet retransmission technique is a simple way of improving the delivery rate. As a retransmission count (R) increases, the effective packet error rate ($E_{L;R} = E_L^{R+1}$) is gradually decreased. For example, when a packet error rate is 50% and a retransmission count is three, the effective packet error rate is lower than 6.5%. However, this technique results in the heavy network traffic in direct proportional to the retransmission count. This heavy traffic consequently incurs a large amount of power consumption. Thus, the retransmission technique does not efficiently improve the delivery rate in terms of power consumption.

The automatic repeat request (ARQ) [14] is a reliable MAC protocol that guarantees the reliable hop-by-hop delivery. Basically, ARQ is classified into three major types depending on the presence of sender and receiver buffers as shown in Figure 1.

First, in the stop-and-wait ARQ, the sender transfers a data packet and waits until it receives the acknowledgement (ACK) packet as shown in Figure 1(a). If the sender does not receive the ACK packet before its retransmission timer is expired, it retransfers the data packet and repeats this procedure until it receives the ACK packet. Since this technique delivers the packets one by one, both the sender and the receiver require a small size buffer. However, this technique at the same time results in a slow packet delivery speed.

Second, in the go-back-N ARQ, the sender transfers a group of data packets without having to wait an ACK packet as shown in Figure 1(b). The sender stores the sent packets in its buffer whose size is W packets. Then, the receiver replies by using a cumulative ACK packet. For example, when the sender transfers packets (N, $N+1$, $N+2$, $N+3$), and the packet ($N+1$) is lost due to an error, the receiver requests to the sender for resending the data packet from ($N+1$). Then, the sender retransfers the data packet ($N+1$, $N+2$, $N+3$) even though the packets ($N+2$, $N+3$) are correctly delivered to the receiver in the first transmission because the receiver node does not have a buffer. As shown in Figure 1(c), the selective-repeat ARQ addresses this drawback by using a receiver buffer. Thus, the selective-repeat ARQ generally provides the best performance among these three techniques.

Next, as partly mentioned before, recently several reliable transports were developed for the wireless sensor networks. These include PSFQ [9] and RMST [7]. PSFQ is mainly used as a reliable transport for multicasting the control data such as a new software image from a base node to sensor nodes [10]. Thus, it is not appropriate for the forward direction reliable transport that uni-casts the data from a sensor node to a base node. One the other hand, RMST is used as a forward direction reliable transport. RMST employs the stop-and-wait ARQ in link layer and a selective NACK (negative ACK) protocol in transport layer. Thus, it ensures the complete end-to-end reliable data delivery. However, the sensor networks are often interested in reliable detection of the collective information provided by the numerous sensor nodes not in their individual reliable reports. Therefore, the complete end-to-end reliable protocols include RMST are



(a) Stop and Wait ARQ (b) Go-Back-N ARQ (c) Selective-Repeat ARQ

Fig. 1. The existing reliable MAC protocols classified by the presence of buffers

not generally applicable for the forward direction reliable transport in the sensor network regime.

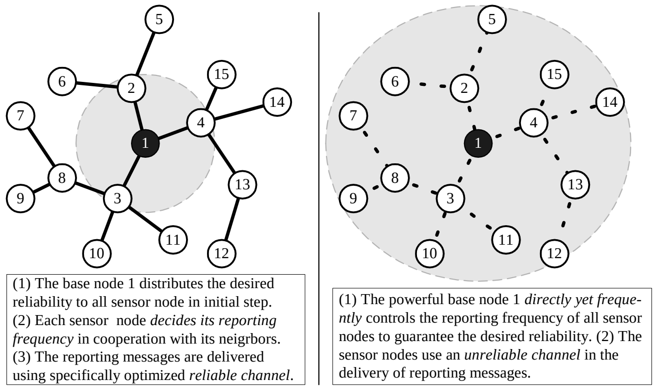
In order to provide a reliable detection of events occupied in the sensor networks, a centralized reliability control technique, namely ESRT [8], was presented. In ESRT, a base node directly controls the reporting frequency of all sensor nodes by using either a multicast protocol or a powerful radio device. However, this centralized transport is not generally applicable to the wireless sensor networks because as it frequently changes the reporting frequency of all sensor nodes, it incurs serious control overheads of the energy consumption and the network congestion. Therefore, we present a decentralized reliable transport for the wireless sensor networks in Section 3.

3 Energy-Efficient Decentralized Reliable Transport

In this section, we briefly compare DRT with the centralized transport of ESRT. Then, we explain the two novel decentralized reliability control schemes and describe the reliable MAC channel that is specifically optimized for DRT.

Figure 2 illustrates the key characteristics of DRT and ESRT. In ESRT, the powerful base node directly controls the reporting frequency of all sensor nodes in a centralized manner. Since the sensor nodes use unreliable channel, the number of successful packet delivery from sensor nodes to the base node is vary depending on the network state, such as number of hops and average packet error rate. Thus, the base node adaptively changes the reporting frequency, but this generally incurs lot of control overhead in terms of time and network traffic. Moreover, it has a strong design constraint that the base node has to directly deliver its control signal to all sensor nodes if it does not use a multicast protocol.

Fortunately, in DRT, the base node does not have to frequently control the all sensor nodes because each sensor node controls its reporting frequency in a decentralized manner as demonstrated in Figure 2(a). We specifically construct DRT based on three key steps.



(1) The base node 1 distributes the desired reliability to all sensor node in initial step.
(2) Each sensor node *decides its reporting frequency* in cooperation with its neigrbors.
(3) The reporting messages are delivered using specifically optimized *reliable channel.*

(1) The powerful base node 1 *directly yet frequently* controls the reporting frequency of all sensor nodes to guarantee the desired reliability. (2) The sensor nodes use an *unreliable channel* in the delivery of reporting messages.

(a) Decentralized Transport (DRT) (b) Centralized Transport (ESRT)

Fig. 2. The decentralized reliable transport vs. the centralized reliable transport

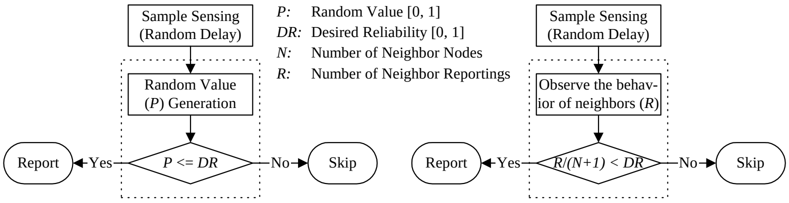
First, in querying step, the base node distributes a query packet that embeds the desired partial reliability degree, which is configured by network users, to all sensor nodes. The query packet also includes the target sensor node conditions, the sample types, the reporting period, the number of reporting counts, and the quantization degree. In order to efficiently diffuse the querying packet, we use a reliable multicasting protocol, such as PSFQ, in this step. Since we assume that the routing topology is fixed before this step in this paper, DRT is orthogonal to any routing protocols, whose goal includes the uniform use of sensor nodes.

Second, in reliability control step, each sensor node makes the reporting decision, whether it will reports its sample data or not, so as to ensure the desired reliability with the minimum energy consumption. We use two novel decentralized reliability control schemes as described in Figure 3.

In the independent reporting scheme, each sensor node stochastically makes the reporting decision. Particularly, the sensor node generates a random rate using its system time and its node ID. If the random rate is lower than or equal to the desired reliability, it reports the sample data as shown in Figure 3(a). Otherwise, it does not report.

Contrastively, in the cooperative reporting scheme, each sensor node cooperates with its neighbor nodes so as to uniformly report their sample data. As shown in Figure 3(b), the sensor node compares the desired reliability with the ratio of the reporting count of its neighbors to the number of its neighbors plus one. It means that when its neighbor nodes locally satisfy the desired reliability, the node does not report its sample data to lessen the energy dissipation. Optionally, the sensor node can omit to report its sample data, if its sample data is quiet similar to the reported sample data of its neighbors.

This cooperative scheme is exemplified in Figure 4 where the desired reliability is 70% and the neighbor node count is three. The sensor nodes can implicitly observe the reporting behavior of their neighbors because it is a wireless network where all packets are broadcasted, and the radio device consumes similar power in both listening and receiving modes. Moreover, since we consider that



(a) Independent Reporting Scheme (b) Cooperative Reporting Scheme

Fig. 3. The decentralized reliability control schemes of DRT

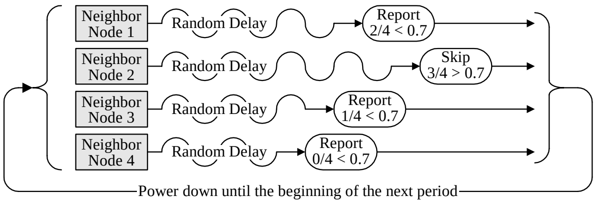


Fig. 4. An example of the cooperative reporting scheme

the neighbor node count is calculated in either routing or querying step, the cooperative scheme does not incurs any extra overhead.

Finally, in reporting step, the sensor nodes use the reliable MAC channel in order to guarantee the desired reliability with these decentralized reliability control schemes. We specifically optimize the reliable MAC channel, which is based on the selective-repeat ARQ for reducing the energy consumption. We present the parameter optimization procedure of the reliable channel such as retransmission timer and the buffer size in Section 4. Furthermore, in order to reduce the overhead of packet header, we propose the packet unification technique that unifies the several sample data packets to one packet. Actually, it is possible because DRT uses the direct diffusion technique [12, 13] that makes the sample data as name and value pairs. We also present the optimization of the packet unification parameter in Section 4.2.

In this paper, we presume that each sensor node can turn off its radio devices as quick as it delivers its all data packets by using the partial state reporting scheme of TAG [11].

4 Performance Evaluations

In this section, we describe the simulation methodology and evaluate the performance of DRT over the existing unreliable and reliable transports.

4.1 Experimental methodology

To study the performance of the various transports, we have developed a byte-level sensor network simulator using Java. The simulator includes various types of sensor nodes that are specifically modeled as finite state machines with software timers and job queues. The simulator core divides the simulation time into units of sending one byte, and it schedules all sensor nodes in every time unit.

The simulator provides two error condition maps as illustrated in Figure 5. The maps consist of a fifty-one by fifty-one matrix of small cells, whose extent is $10m^2$ and whose color means the medium error rate. The darker color means the higher error rate. We assume the average bit error rate to be 0.5% and the error range to be between 0% and 1% according to [4]. We calculate the bit error rate between two nodes by using the average value of their error rates. In fact, Figure 5(a) represents an outdoor error condition, and Figure 5(b) represents an indoor error condition, where cells near to the boundary walls have a high error rate due to the interference of the walls.

The simulator also supports four routing topologies as shown in Figure 6. Figure 6(a) and 6(b) mean random topologies, while Figure 6(c) and 6(d) mean grid topologies. In these topologies, a base node is placed in the center of each map. We used these four routing topologies in combination with the aforementioned two error maps in every experiment, and then we calculated the mean values as summarized in Section 4.2.

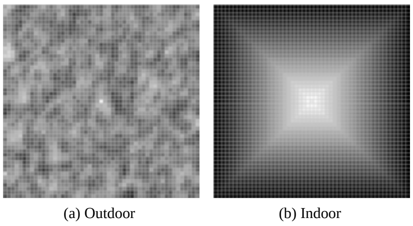

(a) Outdoor (b) Indoor

Fig. 5. Medium error condition maps

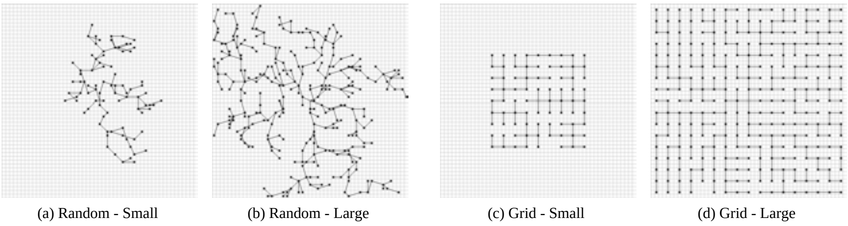

(a) Random - Small (b) Random - Large (c) Grid - Small (d) Grid - Large

Fig. 6. Network routing topologies

We selected the hardware parameters of a radio device based on Mote [2]. For example, we set the radio bandwidth to be 40Kbps, the radio communication radius to be 30 meters, and the radio power consumption to be 5μA in idle state, 4.5mA in either listen or receive state, and 12mA in transfer state.

We preformed a pre-simulation to choose the appropriate software parameters. As a result, we set a retransmission timer of the reliable MAC protocol to be 30-60ms. The retransmission time is dynamically changed depending on the medium error rate. We also set the retransmission timer gap between consequent packets as more than the packet roundtrip time. Because in the simulator all sensor nodes handle the ACK packets as a highest priority job, this configuration removes the useless retransmissions in most cases. We assumed the processing time of a data packet and an ACK packet to be 10ms and 2ms, respectively. We considered the size of packet header and sample message as eight bytes and six bytes, respectively. In every experiment, each sensor node performs one sampling after a random delay at most 200ms.

Finally, we use the partial reliability, the communication time, and the power consumption of a radio device per each sensor node as performance metrics. The communication time is the elapsed simulation time to deliver all reporting messages to a base node. We calculated the power consumption per each node by using the aforementioned radio power model.

4.2 Simulation results

Table 1 summarizes the simulation results of the existing unreliable and reliable transports. First, the results show that the centralized transport with unreliable channel, i.e. ESRT, accomplishes extremely low reliability of 4% in an average case. Fortunately, this technique works very fast and consumes quite low power. When we use the bulk retransmission technique with unreliable channel,

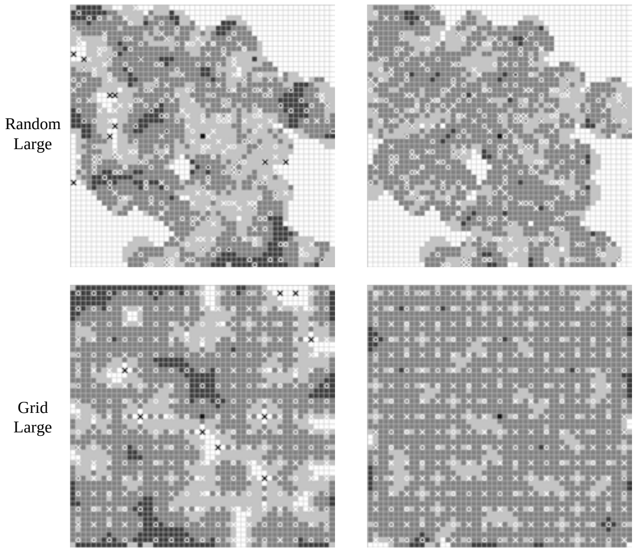
Table 1. Performance summary

Scheme	**Spec.**	**Reliability (%)**		**Time (ms)**	**TX (KB)**	**RX (KB)**	**Power (μA)**
		MIN	**AVG**				
Unreliable - Retransmission - R: Retransmission count	R=0	2	4	223	5	134	731
	R=1	3	5	293	12	137	854
	R=3	4	7	948	38	177	1,385
	R=5	5	8	3,277	97	277	2,681
	R=7	5	10	22,260	329	665	7,730
	R=9	5	10	93,780	897	1,594	19,985
ARQ - Stop and wait - Proposed packet unification tech. - U: Packet unification parameter	U=1	100	100	12,730	117	1,648	9,823
	U=2	100	100	10,352	120	1,554	9,389
	U=3	100	100	11,340	146	1,778	10,852
	U=4	100	100	15,772	178	2,130	13,052
	U=5	100	100	20,859	224	2,557	15,806
ARQ - Selective repeat - U=2 - B: Buffer size in packets	B=2	100	100	10,760	122	1,562	9,450
	B=4	100	100	8,199	133	1,344	8,504
	B=6	100	100	8,188	140	1,294	8,356
	B=8	100	100	8,984	124	1,375	8,539
	B=10	100	100	8,742	155	1,355	8,859
DRT - Independent Rep. - U=2, B=6 - DR: Desired reliability (%)	DR=100	100	100	8,479	143	1,342	8,638
	DR=90	84	91	7,751	129	1,252	7,985
	DR=70	68	71	6,185	91	1,046	6,453
	DR=50	46	51	5,268	60	828	4,947
	DR=30	24	31	3,408	34	589	3,400
DRT - Cooperative Rep. - U=2, B=6 - DR: Desired reliability (%)	DR=100	100	100	8,201	143	1,354	8,692
	DR=90	99	100	7,457	142	1,300	8,408
	DR=70	78	82	6,932	108	1,138	7,141
	DR=50	61	64	5,240	79	935	5,744
	DR=30	44	50	5,060	61	802	4,825

it improves the reliability up to 10% in average cases. However, it at the same time incurs a long finishing time and large power dissipation. Therefore, the centralized transport with unreliable channel is not efficient to provide the high reliability in terms of power consumption and communication time.

We optimized the performance of the reliable MAC channel for improving the delivery speed and reducing the energy dissipation. First, we evaluated the stop-and-wait ARQ with the proposed packet unification technique. The results show that when the unification parameter is two packets, this technique provides the optimal performance. Second, we evaluated the selective-repeat ARQ where the unification parameter is two packets. The simulation results show that the selective-repeat ARQ with the unification technique performs best when the buffer size of both sender and receiver is set to six packets. When the buffer size is larger than six packets, the performance is degraded due to the network congestion and the packet collisions.

In DRT, each sensor node determines the delivery of its sample data. The data packets, which is chose to report, are always delivered to the base node. Contrasted to this, in an unreliable scheme, each sensor node attempts to deliver all sample data. However, some of them are lost in the delivery to the base node because of communication errors. The lost packets uselessly waste the energy of radio devices. This useless energy consumption is avoided in DRT because it uses the reliable channel and makes the reporting decision as early as possible. Therefore, DRT accomplishes the desired reliability with lower energy consumption as compared with the unreliable scheme.



(a) Independent Reporting Scheme (b) Cooperative Reporting Scheme

Fig. 7. Reporting density. (white: none, light gray: low, dark gray: fit, black: over)

Based on these optimal parameters, we analyzed the performance of DRT with two different decentralized reliability control schemes. The results show that DRT with the independent scheme provides the measured reliability more similar to the desired one than DRT with the cooperative scheme in average cases. One the other side, the cooperative DRT always guarantees the desired reliability. Therefore, these two schemes can be alternatively used in various application domains depending on their objectives.

In the sensor networks, we can induce some semantic information by using a part of sample data. The required ratio of sample data is defined as the partial reliability in this paper. DRT provides an infrastructure where users can easily control the partial reliability. We analyzed the performance gains obtained with this partial reliability control mechanism of DRT. The selective-repeat ARQ is used as a complete reliable transport. The result is that DRT notably reduces both the communication time and the power consumption in comparison with the complete reliable transport. For example, when the desired reliability is 70%, the independent DRT and the cooperative DRT reduce the communication time by 24% and 15%, respectively, and the power consumption by 23% and 14%, respectively.

In order to enhance the reliability in the sensor networks, the numerous sensor nodes should uniformly report their sample data to the base node. For example, when we monitor the temperature, we generally require at least one temperature sample per every physical room. Figure 7 visualizes the reporting density of DRT with different reliability control schemes. Here, the white cells mean no reporting, the light gray cells mean lower reporting than the desired reliability, the dark gray cells mean appropriate reporting, and the black cells mean excessive reporting. The figure implies that the cooperative DRT distributes the reporting density more uniformly than the independent DRT due to its local cooperation mechanism.

5 Conclusions

We have presented a decentralized reliable transport mechanism for wireless sensor network. With its unreliable radio channels, a wireless sensor network cannot accurately predict the successful packet delivery rate to the base node. Unlike the previous work, which depends on the powerful centralized base node, our approach makes reporting decisions locally. Using custom-optimized reliable MAC channel, sampled sensing data are sent to the base node. Experimental results show that DRT accurately guarantees the requested reliability while it reduces the power consumption of the radio device and the communication time significantly.

References

1. I.F. Akyildiz, S. Weilian, Y. Sankarasubramaniam, and E. Cayirci, "A Survey on Sensor Networks," *IEEE Communications Magazine, Vol. 40, No. 8, pp. 102-114, 2002.*
2. *The TinyOS and Mote Project, http://webs.cs.berkeley.edu/tos/.*
3. *The Smart-Its Project, http://www.smart-its.org/.*
4. *R. Rubin, "Analysis of Wireless Data Communication," UC Berkeley Technical Report, 2000. (http://http://webs.cs.berkeley.edu/tos/.)*
5. *J. Hill and D. Culler, "A Wireless-Embedded Architecture for System Level Optimization," UC Berkeley Technical Report, 2002.*
6. *J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler, and K. Pister, "System Architecture Directions for Network Sensors," In Proceedings of the 9th ACM International Conference on Architectural Support for Programming Languages and Operating Systems, pp. 93-104, 2000.*
7. *F. Stann and J. Heidemann, "RMST: Reliable Data Transport in Sensor Networks," In Proceedings of the 1st IEEE International Workshop on Sensor Network Protocols and Applications, pp. 102-112, 2003.*
8. *Y. Sankarasubramaniam, O.B. Akan, and I.F. Akyildiz, "ESRT: Event-to-Sink Reliable Transport in Wireless Sensor Networks," In Proceedings of the 4th ACM International Symposium on Mobile Ad-Hoc Networking and Computing, pp. 177-188, 2003.*
9. *C.-Y. Wan, A.T. Campbell, L. Krishnamurthy, "PSFQ: A Reliable Transport Protocol for Wireless Sensor Networks," In Proceedings of the 1st ACM Workshop on Wireless Sensor Networks and Applications, 2002.*
10. *P.V. Krishnan, L. Sha, and K. Mechitov, "Reliable Upgrade of Group Communication Software in Sensor Networks," In Proceedings of the 1st IEEE International Workshop on Sensor Network Protocols and Applications, pp. 82-92, 2003.*
11. *S. Madden, M. Franklin, J. Hellerstein, and W. Hong, "TAG: a Tiny Aggregation Service for Ad-Hoc Sensor Networks," In Proceedings of the 5th USENIX Symposium on Operating Systems Design and Implementation, 2002.*

12. J. Heidemann, F. Silva, C. Intanagonwiwat, R. Govindan, D. Estrin, and D. Ganesan, "Building Efficient Wireless Sensor Networks with Low-Level Naming," In Proceedings of the ACM Symposium on Operating Systems Principles, pp. 146-159, 2001.
13. C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks," In Proceedings of the ACM/IEEE International Conference on Mobile Computing and Networking, pp. 56-67, 2000.
14. G. Fairhurst and L. Wood, "Advice to Link Designers on Link Automatic Repeat reQuest (ARQ)," Request for Comments (RFC), No. 3366, 2002.