A Power-Aware Reliable Routing Algorithm for Wireless Sensor Networks

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***Abstract*—Wireless sensor networks are very much concerned on conserving power and error control coding is a considerable burden on this power conservation. Thus, this paper proposes a diversity based routing algorithm to achieve the reliability in the absence of error control coding. Two diversity combining techniques are also proposed. The simulation results demonstrate that the proposed routing algorithm achieves the reliability that of many simple linear block codes while outperforming some. Moreover, the low complexity due to the absence of error control circuitry, reduces power consumption greatly.**

***Index Terms*—Wireless sensor networks, Power aware routing, Diversity**

I. Introduction

Wireless sensor networks (WSNs) provide immense value in monitoring many of the environments where some of them are hostile and unreachable for humans. Inherently, WSNs are very concerned on power efficiency as the sensor nodes usually run on a battery which is not regularly replaceable or on regenerative low capacity sources such as solar power. Therefore, many power efficient WSN communication algorithms have been developed [1]. At the same time, wireless communications suffer from many adverse effects such as fading, shadowing and noise which introduce bit errors. To overcome the effect of such phenomena, error control schemes are being utilized in general communications. Both forward error correction (FEC) and automatic repeat request (ARQ) are employed in wireless networks. ARQ based communications operates by detecting the errors in the received packets and requesting a retransmission in the event of an error. This process is carried out until the packet is received correctly. In FEC schemes the packet is given an additional capability to correct the errors if present. However, this additional capability comes at the cost of extra bits.

WSNs too are equipped with such error control schemes to add reliability. However, due to its power conservating nature, a large number of retransmissions cannot be tolerated. A modified version of ARQ, hybrid-ARQ (HARQ) is also a preferred candidate for error control in WSN where an incremental error correcting capability is given with retransmissions [2–4]. Here the number of bits being retransmitted is less compared to ARQ and also the error rate is less than in ARQ [3]. Nevertheless, the power consumption at nodes with HARQ is still high due to the retransmissions and the partial and repeated error correction. Thus most of the WSNs rely only on simple FEC schemes for error control, even though their error performance is less compared to HARQ.

Even in a FEC, two factors are critical in WSN environments. High complexity in encoding and decoding consumes additional node power and also and the additional number of bits introduced consumes additional transmit power. Thus, to minimize these additional power consumptions simple high rate linear block FEC codes are usually employed in WSNs [5]. Even then, the error control is a considerable burden on the power sensitive wireless sensor nodes.

To overcome the above issue, this paper proposes a power aware routing algorithm in place of error control, where the key concept is to route the same data packet to two coordinator / sink nodes. These will in turn be communicated to a central point where a diversity combining technique is used to extract the information. With diversity, the reliability is to be at an acceptable level even in the absence of any error control coding. On the other hand the absence of the complex coding operations is expected to save a lot of power at the relay nodes. The rest of the paper is organized as follows. In Section II, the system model is presented. Section III presents the proposed power aware routing algorithm followed by a complexity analysis and the simulation results and discussion in Sections IV and V. Finally Section VI, concludes the paper highlighting the possible future research areas.

II. System Model

In this paper we consider a wireless sensor network with low power sensor / relay nodes where the information captured at a sensor are relayed to a sink node through multiple hops. Furthermore, a dynamic routing scheme based on the Dijkstra algorithm is considered [6]. The concept of channel state aware dynamic routing is adopted in view of an improved error performance compared to that of static routing [6]. However, unlike in conventional dynamic routing, the algorithm is modified to route the same packet to two different data sink nodes as shown in Fig. 1. Note that the bit estimation is carried out only at the central station and the intermediate nodes only perform relaying.

It is further assumed that the channels are Rayleigh block faded where the fading coefficients are static for the duration of a block of bits. Moreover, it is assumed that the

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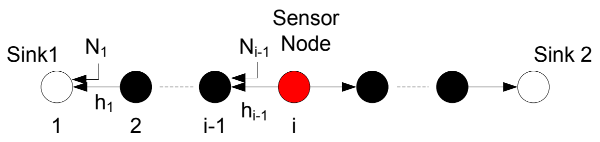

Fig. 1. Two way dynamic routing

complete channel state information of all relay channels is available at both the sink nodes. Let the fading coefficients of the channels from the i-th source node to sink node 1 be $\mathbf{h} = (h_{i-1}, h_{i-2} \ldots, h_2, h_1)$. For simplicity, it is also assumed binary phase shift keying (BPSK) modulation with symbols $s_i \in \{-1, +1\}$. Hence, for a data bit generated at the i-th node, the received signal at the sink node 1 is $y = \left(\prod_{j=1}^{i-1} h_j\right) s_i + \left(\prod_{j=1}^{i-2} h_j\right) n_{i-1} + \ldots + n_1$ where $(n_1, \ldots, n_{i-1})$ are the independently and identically distributed (iid) complex Gaussian noise samples with zero mean and σ^2 variance per dimension, added at the relay nodes and the sink node antennas.

III. Proposed Routing Algorithm

The proposed routing scheme consists of two modifications to the existing routing algorithm. In view of the simplicity of processing at the sensor nodes, the error control coding is eliminated. However to retain the reliability, a diversity gain is introduced by collecting the same information at two sink nodes at two different locations. Assume that there exists a 100% reliable means of communicating this information to a central monitoring station.

A. Cooperative routing

The communication of one data packet corresponding to one sensor node takes place in a certain time duration while no other node is communication its data. In order to achieve this requirement, a perfectly synchronized communication is also assumed. Due to the very low volume data communication requirement in many of the sensor networks, this synchronization assumption is reasonable and can be implemented without much difficulty.

With known channel coefficients $\mathbf{h}$, $y|s_i$ is a Gaussian random variable with mean $\mu_T = \left(\prod_{j=1}^{i-1} h_j\right) s_i$ and variance $\sigma_T^2 = (\prod_{j=1}^{i-2} h_j)^2\sigma^2 + \ldots + h_1^2\sigma^2 + \sigma^2$.

Thus, $y|s_i = H_i s_i + N_i$ where $H_i = \prod_{j=1}^{i-1} h_j$ and $N_i \sim \mathcal{N}(0, \sigma_T)$.

$$\begin{aligned} Pr(s_i = \xi|y) &= \frac{Pr(y|s_i = \xi)Pr(s_i = \xi)}{Pr(y)} \qquad (1) \\ &= \frac{1}{2Pr(y)} \times \frac{1}{\sqrt{2\pi\sigma_T^2}} e^{-\frac{(y-\mu_{T,\xi})^2}{2\sigma_T^2}}, \end{aligned}$$

where $\xi \in \{-1, +1\}$.

Then,

$$\begin{aligned} LLR(s_i|y) &= log\left(\frac{Pr(s_i = +1|y)}{Pr(s_i = -1|y)}\right) \qquad (3) \\ &= log\left(\frac{\frac{1}{\sqrt{2\pi\sigma_T^2}} e^{-\frac{(y-\mu_{T,+1})^2}{2\sigma_T^2}}}{\frac{1}{\sqrt{2\pi\sigma_T^2}} e^{-\frac{(y-\mu_{T,-1})^2}{2\sigma_T^2}}}\right) \\ &= \frac{2y\mu_{T,+1}}{\sigma_T^2} \\ &= \frac{2y\left(\prod_{j=1}^{i-1} h_j\right)}{\sigma_T^2}. \end{aligned}$$

Note that $\mu_{T,\xi}$ represents the mean with $s_i = \xi$.

B. Diversity Combining

As already stated earlier, the collected data by the two sink nodes are then communicated to a central location via 100% reliable links. Corresponding to a certain bit generated at the i-th source node, now there are two y signal informations (y_1 from sink 1 and y_2 from sink 2) received at the central node. These informations are then diversity combined to form a single binary estimate for the transmitted data bit. For the combining, we propose two schemes.

1) Best estimate selection (BES): First, we employ a reliability based selection scheme where the reliability of each information is calculated as $R(s_i|y) = |LLR(s_i|y)|$. Thereafter, the output with the highest reliability is selected as the final estimation.

$$s_i = \begin{cases} \xi & \text{if } R(s_i|y_1) > R(s_i|y_2) \\ \xi' & \text{otherwise,} \end{cases} \qquad (4)$$

with ξ and ξ' representing the estimated symbol values from sink 1 and sink 2 informations, respectively.

2) Weighted average method (WA): BES approach ignores the information gathered through one of the paths. Therefore, this subsection considers a scheme to harness the information from both the paths in view of a better combining. Let us consider a maximal ratio combined [7] signal $y = H_1 y_1 + H_2 y_2$, where H_1 and H_2 correspond to two diversity routes through which the information is passed. $H_1 = \prod_{j=1}^{i-1} h_j$ and $H_2 = \prod_{j'=1}^{i'-1} h_{j'}$. As y_1 and y_2 are both Gaussian random variables y too is a Gaussian random variable. Then $\sigma_y^2 = \left(H_1^2 + H_2^2\right)\sigma^2$. Furthermore,

$$\begin{aligned} LLR_y(s_i|y) &= \frac{2}{\sigma_y^2} yH \\ &= \frac{\kappa}{\sigma^2}(H_1 y_1 + H_2 y_2) \\ &= \kappa\frac{(LLR_1(s_i|y_1) + LLR_2(s_i|y_2))}{2} \qquad (5) \end{aligned}$$

where $\kappa = \frac{H_1+H_2}{H_1^2+H_2^2}$.

$$s_i = \begin{cases} +1 & \text{if } LLR_y(s_i|y) \geq 0 \\ -1 & \text{otherwise,} \end{cases} \qquad (6)$$

IV. Complexity Analysis

In this section, the complexity advantage gained by the proposed algorithm is analyzed. The proposed algorithm requires t transmissions in average for a t number of nodes along the two paths. Therefore for a message with l bits, it requires only $t \times l$ bits. On the other hand, the coding with a rate K will introduce $\frac{l}{K}$ bits per message. Therefore, for $K < 0.5$, more transmissions are required for the conventional routing with channel coding compared to the proposed algorithm.
We also investigate the power saving by avoiding the encoding and decoding. Note that with the proposed algorithm, no coding operation is required and only the real operations involved in calculating μ_T and σ_T^2 are to be carried out once per each block of data. On the other hand, Table I lists the required average numbers of real operations (additions and multiplications) in the conventional relaying together with several commonly used channel codes for a block with $l = 100$. It is clear that the coding adds a lot of additional complexity. Further, smaller i values result in smaller complexities in detection.

TABLE I
Number of Real Operations Required with End-to-End FEC Coding

Algorithm	For detection	For Coding
Proposed	$(i-1)\left(\frac{i}{2}+2\right)+100$	0
With Hamming (7,4) coding	$(i-1)\left(\frac{i}{2}+2\right)+175$	1950
With LDPC (63,37) coding	$(i-1)\left(\frac{i}{2}+2\right)+170$	21200

V. Simulation Results and Discussion

In this section, the bit error rate (BER) performance of the proposed algorithm is compared to that of single path routing with several simple FEC block codes. These experiments are based on iid Rayleigh block fading channels with unit variance between the nodes in the WSN. A comparison of the BER performance of the proposed routing algorithm and the conventional channel coding algorithms are presented in Fig. 2. It clearly demonstrates that the proposed WA scheme is outperforming the BER performance of a simple Hamming code, a Reed Solomon (RS) code and a very short low density parity check (LDPC) code considered while having almost the same or better BER performance with BES scheme.

VI. Conclusion

A novel routing algorithm is proposed for routing the information captured at a node in a WSN which uses a diversity reception with two sink nodes. This approach has shown to be maintaining the error performance obtained by the use of common error control codes in WSN. This is in expense of only a minor or no increase in transmit power requirements. At the same time the diversity approach has proven to be completely eliminating the complex mathematical operations involved in encoding and decoding, thus saving a considerable amount of power.

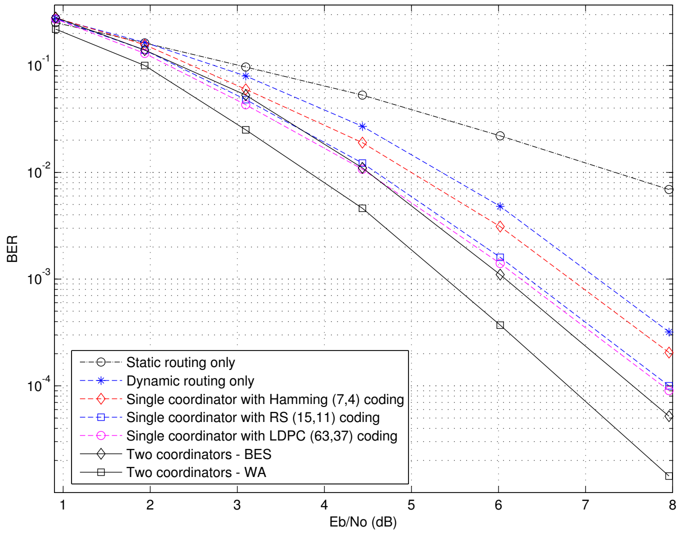

Fig. 2. Comparison of BER performance.

The error performance of the above algorithm can be further increased by adding more diversity paths to information transfer. However, this will lead to more power consumption for transmission due to an increase number of transmissions. Investigations on an optimum scheme would be an interesting research topic.

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