A Channel Aware Contention based Forwarding scheme in Wireless Sensor Network

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Abstract—This paper presents a channel aware contention based forwarding scheme (CACF) for wireless sensor network (WSN). In order to improve the probability of correct packet transmission in wireless channel and ensuring successful contention, CACF selects the appropriate relay node by the integrated consideration of access probability, routing cost metrics and wireless channel characteristics. In the scheme, a well-defined access space mechanism (ASM) is proposed and used as criterion for relay selection during each contention round. The simulation results show that CACF achieves better network performance in terms of packet delivery ratio and improves the node efficiency consequently.

Keywords-forwarding; crosslayer; WSN

I. INTRODUCTION

Forwarding scheme [1] is a fundamental component of the protocol stacks in multi-hop wireless sensor network (WSN). It specifies how to select the appropriate “next-hop” node for relaying data. In WSN, the forwarding schemes should be simple [2], energy-efficient [3] and robust [4].

The researches on forwarding algorithms in multi-hop WSNs have attracted a substantial amount of attention during the past few years [2–8]. In [7], a typical location-based forwarding scheme named GeRaF is proposed and relay node is selected via contention among receivers. The authors in [5] present an algorithm with the optimal trade-off between proximity and link cost based on a normalized advance metric NADV. Reference [2] proposes CCMR, which is an integrated MAC/routing forwarding scheme. The scheme selects the next hop by considering cost-dependent access probability where cost accounts for the goodness of nodes. However, none of them considers the time-varying channel’s influence on the performance of forwarding schemes.

In this paper, we present a novel cross-layer forwarding scheme called channel aware contention based forwarding (CACF). For the purpose of improving the probability of correct packet transmission and ensuring successful contention, CACF elects an optimal relay node through contention, by synthesizing the cross-layer conditions of nodes during each hop. In the scheme, a cross-layer election mechanism called access space mechanism (ASM) is employed. ASM not only considers the access probability and routing cost metrics but also exploits the channel condition. Ground on ASM, which is a criterion for contention, a proper relay node is consequently determined. As shown in the simulations, the proposed CACF scheme achieves better performance in terms of packet delivery ratio and contention performance compared to other forwarding scheme.

This paper is structured as follows. The system model is described in section 2. Section 3 presents the CACF scheme and the novel ASM mechanism. In section 4, we provide simulation results of CACF compared with CCMR. Conclusions are given in the last section.

II. SYSTEM MODEL

We consider a wireless sensor network with N static nodes randomly located on a rectangular domain area. Every node in the network generates data and all packets are ultimately delivered to sink.

A. Forwarding Area

In our scheme, every node is preassigned with a certain forwarding area (FA). To get enough candidate nodes for relay and improve the overall performance of our scheme, the maximum forwarding area (MFA) [6] is adopted here. As shown in Fig. 1, for the current forwarding node i, MFA of node i is the overlap region of two circular areas: the transmission circle of node i and the circle of sink. We define that contender set \( C'_N \) of node i is consisted of all the active nodes in MFA of node i. Packets transmitted from node i to any node of \( C'_N \) could make a positive geographical

![Figure 1. Maximum forwarding area in CACF](image-url)
progress towards the sink.

B. Contention Procedure

When node $i$ has data to forward, nodes in the contender set $C'_N$ would contend to be relay node. We assume that the network is time-slotted. Contention works in rounds until the relay node is decided. Every round lasts $R$ slots and works as following. Firstly, node $i$ sends an request (REQ) to all nodes of $C'_N$. Upon receiving the REQ, each node of $C'_N$ then transmits a reply (REP) back to node $i$ at a specific slot. Here the slot is chosen based on the ASM mechanism as described in III.

C. ETC Model

Each contender in the MFA is endowed with an Error-Token-Cost (ETC) model. For $\forall j \in C'_N$, $(e_j, t_j, c_j)$'s $j$ dedicates the ETC characteristics of node $j$ which resides in the MFA of node $i$.

$e_j$ is the probability of packet error transmission between node $j$ and $i$. It can be calculated as the function of probability of bit error (PER). Here we assume an additive white Gaussian noise (AWGN) and binary phase shift keying (BPSK) modulation. According to [9], PER of node $j$ is obtained as

$$P_{e_j, BPSK} = Q(\sqrt{\frac{2E'_j}{n_0}})$$

(1)

here $E'_j$ is the energy per bit of node $j$, $n_0$ is a noise spectral density.

Thus we get $e_j$ in ETC model as

$$e_j = 1 - Q(\sqrt{\frac{2E'_j}{n_0}})$$

(2)

where $L$ is the packet length.

The $t_j$ of ETC model is the token of node $j$, which is a number randomly picked in $[0, 1]$ at the beginning of each contention round. In our scheme, token $t_j$ can be regarded as the access probability of node $j$ without considering the channel condition or routing metrics [10]. To increase the fairness of access and to balance the energy of the network, we tend to choose node with lesser token as the relay.

The last parameter $c_j$ denotes the cost of node $j$. Associated with several routing parameters, cost indicates the suitability of a node to act as the relay.

$$c_j = 1 - (en_j / EN)(d_j / D)$$

(3)

As described above, the ideal relay node is the one with the minimum error, token, and cost value within the contender set in MFA.

III. Channel Aware Contention Based Forwarding Scheme

A. Scheme Outline

According to the contention procedure, contenders of $C'_N$ in MFA contend to be relay node of the forwarding node. Firstly the forwarding node $i$ sends REQ packets to all contenders of $C'_N$. Here we consider a network where all nodes are synchronous. As soon as REQs are received, the R-slot contention starts and nodes of $C'_N$ contend to be relay. With ETC model, each contender can locate a point in the three-dimensional coordinate as shown in Fig. 2. Each node selects the slot corresponding to the smallest access space (described detailedly below) containing its point, and transmits REP back to node $i$ at this specific slot. In Fig. 2 there is no node in $S_1$, so none of the nodes can access the channel in the first slot. For slot 2, only node $n_2$ is contained in $S_2$; therefore $n_2$ transmits its REP back to node $i$ in slot 2.

To proceed with the analysis, we secondly describe the contention results.

- **Silent**: If no node chooses slot $r$, we say slot $r$ is silent.
- **Collision**: If two or more nodes pick slot $r$, there is a collision in slot $r$.
- **Win**: a contender wins in slot $r$ if and only if it is the only one to choose slot $r$, and all others choose later slots.

We claim that a contention is successful if and only if a contender wins in some slot in $1,...,R$. The winner will access the channel and relay the data. And in the example of Fig. 2, node $n_2$ is the winner.

If collision or silent happens at a slot, the current contention fails. If contention fails, forwarding node $i$ starts a new contention round after a stochastic period of time. Even if contention is successful, the winner may not the one with the best ETC characteristics of all contenders in $C'_N$. The
access space mechanism (ASM) is proposed here to minish the probability of contention failure and selecting bad relays.

B. Access Space Mechanism

Before contention, a series of access spaces are determined as criterions for slot selection. Each access space is modeled as a cube spanning over axises of error, token and cost as shown in Fig. 2. Hence, \( \forall \text{slot } r \in \{1...R\} \), access space \( S_r \) is represented by a ternary operator \( (s_{r}, s_{r}', s_{r}'') \), where \( s_{r}', s_{r}'', s_{r}'' \in [0,1] \). Here, \( S_1, S_2, ..., S_R \) is an increasing sequence. To go on with description below, we now analyze the characteristics of each subspace.

- **Error**

  Without loss of generality, we define signal-to-noise ratio (SNR) at contender node \( j \) as

  \[
  SNR_j = \frac{E_j}{n_0} \quad j = 1, 2, \cdots, R
  \]

  We use Rayleigh distribution to characterize the time-varying channel fading. Thus, SNR is an exponential distribution, whose probability density function (pdf) is

  \[
  f(SNR) = \lambda e^{-\lambda \cdot SNR}, \quad \lambda = \frac{1}{SNR}
  \]

  According to Eq. (2), we have

  \[
  s_r' = 1 - \left(1 - Q(\sqrt{2SNR_r})\right)^j.
  \]

  From Eq. (6), we know that error is a monotonic one-to-one mapping function of SNR. For the sake of simplicity, we rewrite Eq. (6) as

  \[
  s_r' = f(SNR_r).
  \]

  Here, \( f(\cdot) \) is monotone one-to-one mapping function. Hence, the probability that error falls in the interval \( (0, s_r') \) is identical to the probability that SNR falls in \( (0, SNR_r) \).

  \[
  P_e(0, s_r') = P_{SNR}(0, SNR_r).
  \]

  So the probability that error lies in \( (0, s_r') \) is

  \[
  P_e(0, S_{r}) = \int_{0}^{SNR_r} f(SNR) \, dSNR
  = \int_{0}^{SNR_r} \lambda e^{-\lambda \cdot SNR} \, dSNR
  = 1 - e^{-\lambda \cdot SNR_r}.
  \]

- **Token**

  The token of nodes is uniformly distributed in \( [0,1] \), so the probability that token locates in \( (0, s_r') \) is

  \[
  P_t(0, s_r') = s_r'.
  \]

- **Cost**

  Similar to token, the cost of nodes is uniformly distributed in \( [0,1] \). Thus, probability that cost lies in \( (0, s_r') \) is

  \[
  P_c(0, s_r') = s_r'.
  \]

  From the above characteristics, we know that access space is indicated with values from error, token and cost subspaces which are independently with each other. So the probability that contender node \( j \) locates in access space \( S_r \) is that

  \[
  P\{S_r\} = P_e(0, s_r')P_t(0, s_r')P_c(0, s_r')
  \]

  To select relay node with optimal ETC parameters, we should take into account factors of the three subspaces synthetically and make the weight of each factor balanced. So the solution of Eq. (12) should be

  \[
  P_e(0, s_r') = P_t(0, s_r') = P_c(0, s_r') = \frac{1}{3}P\{S_r\}.
  \]

  With Eq. (13), the values in each subspace are calculated as following.

  \[
  SNR_r = -\frac{1}{\lambda} \ln\left(1 - \frac{1}{3}P\{S_r\}\right)
  \]

  We can acquire the factors in error subspace with Eq. (7). And values in token and cost subspaces are as follows.

  \[
  s_r' = \frac{1}{3}P\{S_r\}, \quad s_r'' = \frac{1}{3}P\{S_r\}
  \]

  When \( r = 0 \), \( s_0'' = s_r' = s_r'' = 0 \).

  So far, the access spaces can be expressed as the function of \( P\{S_r\} \), which is the crucial parameter in ASM. In the following, we give the solution of \( P\{S_r\} \). \( \forall j \in C_N \), node \( j \) can locate a corresponding point according to its ETC model \((e_r, t_j, c_r)\). Node \( j \) selects slot \( r \) corresponding to the smallest access space containing its point. It means that node \( j \) picks slot \( r \) only when its point lies in between \( S_r \) and \( S_{r+1} \). Thus the probability that a node picks slot \( r \) is that

  \[
  P(r) = P\{S_r\} \cdot P\{S_{r+1}\}.
  \]
It has been verified in [11] that if $N \geq 2$ contenders picks a slot $r$ with probabilities $p^*_r$, $r \in \{1,2,\cdots,R\}$, the probability that a single node accesses the channel during a given contention round is maximized.

$$p^*_r = 1 - \frac{f_{r-1}(N)}{N - f_{r-1}(N)} (1 - p^*_1 - p^*_2 - \cdots - p^*_{r-1})$$ \hspace{1cm} (17)

Here $f_s(N)$ is defined as $f_1(N) = 0$, and $f_s(N) = \left( (N-1)/(N-f_{s-1}(N)) \right)$ for $s \geq 2$.

Therefore, the key of successful contention is to choose slot according to the distribution of Eq. (14).

$$P(S_r) \cdot P(S_{r-1}) = p^*_r.$$ \hspace{1cm} (18)

The probability $P(S_r) \ r \in \{1\ldots R\}$ can be expressed in an iterative form as

$$P(S_r) = P(S_{r-1}) + p^*_r.$$ \hspace{1cm} (19)

When $r = 0$, $P(S_0) = 0$. In a recursive way we can find the sequence of $P(S_1)$, $P(S_2)$, ..., $P(S_R)$, with which the access spaces in ASM are finally determined.

IV. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed CACF through simulations. In the simulations, we consider a sensor network where $N = 50$ nodes are randomly distributed in a square area. Sink node is located in the left bottom of the area. Each node except sink generates traffic according to a Poisson process with intensity $\lambda$ packets per second per node. We use Rayleigh distribution to characterize the time-varying channel fading. The SNR changes according to an exponential distribution as shown in Eq. (5). We assume a perfect SNR estimation and the PER can be calculated under the given modulation and code scheme. The BPSK modulation with no channel coding is employed. Other parameters used in the simulation are listed in Table I.

The proposed CACF is compared with the existing scheme CCMR-NRG [3] in terms of packet delivery ratio (PDR) and channel contention performance. PDR is defined as the total number of received packets divided by the total number of packets generated. This metric reflects the ability for a forwarding scheme to guarantee the successful packets transmission. For channel contention performance, channel contention duration (CCD) and probability of successful contention (PSC) are considered. CCD indicates the efficiency of electing a next hop.

Fig. 3 shows the PDR for CACF and CCMR schemes with average SNR varying from 5 to 15 and packets generation rates $\lambda$ are 0.02pks/s and 0.08pks/s. As shown, CACF obtains better performance than CCMR in both rates. As expected, CACF performs much better especially at low SNR when PER is very high. Compared to CCMR, CACF has an average 38.8% increase of PDR when $\lambda = 0.08pks/s$ and an average 63.6% increase when $\lambda = 0.02pks/s$. This is because that CACF introduces a well-defined ASM mechanism, which considers not only the access probability and routing cost metrics, but also wireless channel characteristics. Hence, CACF can intelligently avoid nodes with high PER. In contrast, CCMR dose not account for channel condition, and suffers from error packets transmission.

![Figure 3. PDR vs average SNR.](image)

![Figure 4. PDR vs packets generation rate.](image)
In Fig. 4 we show comparison of PDR according to the packets generation rate $\lambda$ when average SNR equals to 8. Obviously PDR drops for both CACF and CCMR as $\lambda$ increases. CACF performs better than CCMR all the time. It is due to ASM mechanism that CACF can avoid channels of large PER with high probability.

The results on the channel contention are given in Fig. 5 and Fig. 6. Fig. 5 shows the CCD versus packets generation rate $\lambda$. For both schemes, CCD augments as $\lambda$ increases. As we can see, the CCD of CACF is a bit higher due to the incorporation of channel condition while choosing the relay node. However, this increase does not affect the whole performance of forwarding scheme CACF. As shown in Fig. 6, PSC of both schemes are extremely close to 1, which also means high forwarding efficiency of CACF.

V. CONCLUSIONS

In this paper we present a novel channel aware contention based forwarding scheme for wireless sensor network. CACF selects relay node with the help of a well-defined ASM mechanism, which incorporates access probability, routing cost metrics and wireless channel characteristics. Numerical results show that even in face of poor channel condition, CACF can still improve the packet delivery ratio and guarantee successful contention.

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REFERENCES


