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A Path Select Algorithm with Error Control Schemes and Energy Efficient Wireless Sensor Networks

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Abstract

A wireless sensor network consists of a large number of sensor nodes that are spread densely to observe the phenomenon. The whole network lifetime relies on the lifetime of the each sensor node. If one node dies, it could lead to a separation of the sensor network. Also a multi hop structure and broadcast channel of wireless sensor necessitate error control scheme to achieve reliable data transmission. Automatic repeat request (ARQ) and forward error correction (FEC) are the key error control strategies in wire sensor network. In this paper we propose a path selection algorithm with error control schemes using energy efficient analysis.

Keywords: *wireless sensor network, error control scheme, ARQ, FEC, energy efficiency.*

I. Introduction:

With the advancement of micro-electro-mechanical technology, wireless communication and digital electronics have enabled the expansion of low cost, low power, small size, multifunctional sensor nodes that can be aggregated to make up of a wireless sensor network. In the literature, several energy-aware routing protocols have been presented for wireless sensor networks, such as Low-Energy Adaptive Clustering Hierarchy (LEACH) [1], Energy-Aware Ad-hoc On Demand Distance Vector (AODV) [2], and Minimum-Transmission-Energy (MTE) routing protocol [1]. LEACH is a cluster-based routing protocol that utilizes randomized rotation of cluster heads on a round basis. This process enables to evenly distribute the high energy dissipation load as the cluster head over the sensor nodes in the network. Energy-aware AODV increases the lifetime of a network by routing around the nodes that are running low in battery. In addition, it turns off the radio interfaces dynamically during the periods when the nodes are idle. MTE is a routing protocol that selects the route with minimum transmission energy to the destination. In MTE routing, the nodes closest to the base station are heavily used to route packets to the base station. Thus these nodes will die out quickly due to their high energy dissipation.

In [3], an optimization metric of energy efficiency is proposed. This model exactly describes the energy efficiency in sensor networks and many subsequent researches [4], [5], [6] are based on this model. [3] Examines the energy efficiency of ARQ and indicates that retransmission strategy of ARQ cannot improve the energy efficiency in sensor networks. Nevertheless, this conclusion is not accurate or comprehensive.

In this paper, we prove that energy efficiency of ARQ technique is independent of retransmission attempts and is unchangeable with the number of retransmission. In [4], [3], energy efficiency of FEC is studied. They reveal that the energy efficiency of BCH code outperforms any other channel codes due to its low encoding and decoding energy consumption. Accordingly, BCH code is used in our work. In this paper, the mathematical analysis for energy efficiency of FEC is presented. The result of our analysis reveals that there is an optimum FEC scheme with the largest energy efficiency for a target communication distance and packet size. The optimum FEC scheme is presented in this paper. Moreover, ARQ is compared with FEC in terms of energy efficiency. The cases where ARQ outperforms FEC and where FEC is more energy efficient are analyzed. According to our results, a location aware sensor node could choose the optimum error control scheme based on foregone information about communication distance and packet length. Besides, to the best of our knowledge this paper is the first work to compare ARQ with FEC schemes in any packet size and communication distance. The rest of this paper is organized as follows:

In Section II we propose a path selection algorithm with energy efficiency for wireless sensor networks. AODV is used as the baseline routing protocol and our work focuses on how to make it energy efficient. In Section Ill mathematical analysis for energy efficiency of error control schemes is provided.

II.A Path selection algorithm with energy efficiency

Minimizing the energy consumption is an important factor for the protocol design. In this section, we consider not only minimization of the energy required for transmission, but also the available energy in the nodes when deciding a "right path". A "right path" means that among many possible paths, it is a path consisting of the nodes that have enough energy for transmission and it has the highest selectivity, which will be defined below in this section. The source would not pick such paths that have low energy, even though they are the ones with minimum energy consumed for transmission. If these paths are selected, they would die out more quickly than other paths that have enough energy. It will affect the network lifetime.

Figure 1.

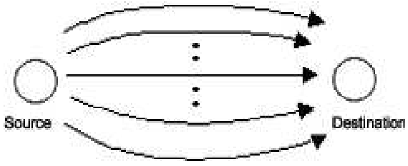


Figure 1(a). Many Possible Paths

Fig.1(a) shows that there exist many possible paths when a source asks for a new path to a destination. For path selection, we take the node energy in the paths into account. The available energy *Ea, pi* for a particular path *pi* is defined as the sum of the available energy of each node on that path. Whenever this particular source sends a packet to the same destination, a path is required from the source to the destination. Therefore, the concept of round can be brought in. When the source requests a path to the destination for the first time, the source will choose a "right path" among many paths found by considering all the factors such as node energy and the number of times this path has been selected. This is a round 1 and it continues to go on whenever the source needs a path to the same destination for transmission. The difference between the traditional routing protocol MTE and our protocol is that the MTE protocol only works in an energy consumption point of view. However, we also consider the available energy in the nodes for each path. –

MTE protocol: min (*Ec, p*1, ... ,*Ec, pn*)

Ec,pi denotes the energy consumed for transmission in a certain path *pi*.

- Available energy: *Ea,p*1, *Ea,p*2, *Ea,p*3, ... *Ea,pn*. – (1)

There are two requirements on how a particular path *pi* is selected:

$$E_{a,pi} > E_{c,pi} \qquad - (2)$$

$$S_{pi} = \frac{P(pi)}{1 - P(pi)\left(k \bmod \frac{1}{P(pi)}\right)} \frac{E_{a,pi}}{E_{m,pi}} \qquad - (3)$$

In the first requirement, it shows that the available energy in a certain path should be larger than the energy consumed for transmission. This is an obvious condition that must be satisfied, otherwise the transmission would be aborted on the way before the destination. In the second requirement, *Spi* stands for selectivity of the path *pi* being selected as a right path. Among all the values of the selectivity, the path that has the largest value will be selected as a right path. The maximum value of the selectivity is 1. *P*(*pi*) is the desired probability for the path *pi*. Normally, it is determined depending on the number of paths n found by the route discovery procedure, as shown in Fig. 1(a). In this case, the desired probability is set to 1/n for each path, so that all the discovered paths can be used equally, thereby maximizing the network lifetime in terms of energy. On the other hand, it is possible to give priority to some path by increasing the desired probability. For example, if the traffic type is delay-sensitive (e.g., urgent event), priority is given to the path with shortest delay, so that this path can be chosen first. Also, if a certain path retains the available energy close to the consumption energy, the desired probability is lowered enough to prevent this particular path from being selected, because it would cause an energy drain of the path once used. Besides the desired probability, the other factor that affects the path selectivity S is the round k in the first term of the equation above. If a source has discovered n paths to a given destination, one cycle is formed with n rounds between these two nodes, and the desired probability is also determined at this point. Normally, the value of the desired probability is changed on a cycle basis. Each cycle starts from round 0 and ends with round n-1. Whenever one of n paths is used to send a packet to the destination, the round value increases by one until the last round n-1. Once a certain path is chosen, the selectivity of that path is set to 0 so that it cannot be used again during this cycle. For any other path, the selectivity continues to increase according to the increment of the round value, as long as it is not chosen. Finally, the first term of the selectivity equation approaches to one so that it will be chosen during this cycle. The reason why a certain path even with the higher available energy is used only once at each cycle is because the environment of wireless sensor networks is changing fast in time due to the wireless links, mobility, or node energy consumption for local processing and so on. Therefore, if the source has another data to send to the same destination after one cycle ends, it executes the route discovery procedure again to find new paths and start a new cycle by reflecting the updated network environment. In the second term of Eq. (3), *Em,pi* represents the maximum energy for the path *pi*. Therefore, if nodes have low available energy, then the value of this fraction will be small (i.e. close to 0), because the value of *Ea,pi* is small and the value of *Em,pi* is large. This means if there is not enough available energy, then such a path will not be chosen due to the small value of the selectivity. In contrast, if nodes have full of energy, then the value of this fraction will be very large (i.e. close to 1), because the value of *Ea,pi* approaches to the maximum energy. As a result, such a path is likely to be chosen as a right path unless there is any larger value than this. Fig. 1(b) summarizes our path selection algorithm.

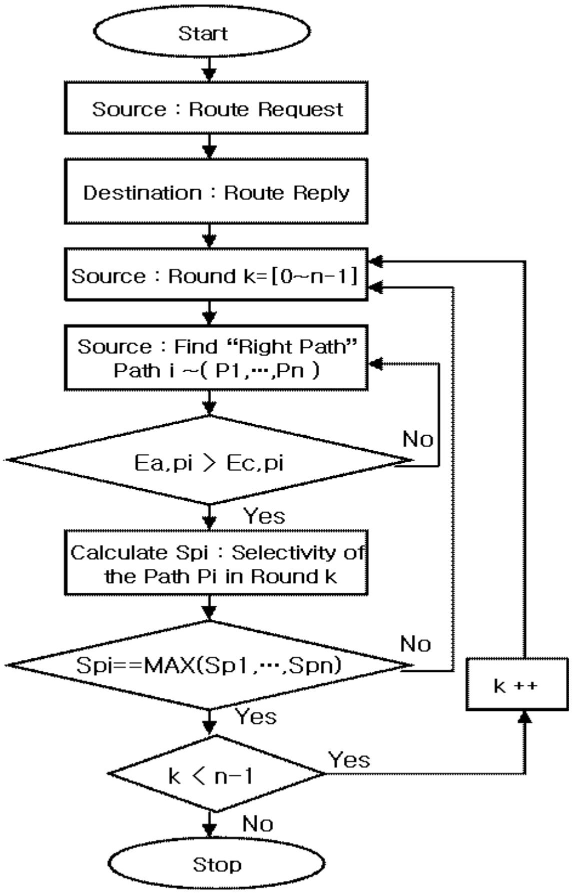


Figure 1(a). Path Selection Algorithm

II.B Protocol Description

Since AODV is used as the baseline routing protocol, our protocol operates almost in the same fashion as AODV [8]. Due to the on-demand nature, it discovers routes only when they are needed. When a source requires a path to a particular destination, the route discovery procedure is initiated by broadcasting a route request (RREQ) packet. The RREQ packet is flooded to the entire network in order to find a path to the destination. When nodes receive this packet, they record a reverse route back towards the source. After that, the RREQ packet is re-broadcast to their neighbor nodes. If the same RREQ packet is received, it is just discarded. In this process, every node in the network will get the RREQ packet. When this RREQ packet reaches the destination, it sends a route reply (RREP) packet back to the source. While the RREP packet comes toward the source from the destination, the available energy field in the RREP packet sums up all the available energy of the nodes on the route between the source and the destination. The available energy field should be added in the RREP packet. If there is any relay node that has the available energy less than or close to the node energy consumed for transmission, then this node just discards the received RREP packet so that the corresponding path may not be considered as one of the discovered paths. Assuming the initial node energy is uniform for all the nodes, multiplication of the number of nodes and the initial node energy indicates the maximum energy for this particular path. However, since the initial node energy may be different for each node in real situation, its value is measured and kept in the memory when the battery starts to operate. Like the available energy, the maximum energy can be obtained by summing up the initial energy of every node on the route as the RREP packet travels from the destination to the source. For the maximum energy, the maximum energy field should be also added in the RREP packet. When all the RREP packets are received from the destination, the source can calculate the selectivity for each path and choose a path with the maximum value among all the found paths. Then, the data can be sent and received along this route. For active routes, nodes keep monitoring the link status. When a link in an active route breaks, it is detected and a route error (RERR) packet is generated to notify other nodes that the loss of that link has occurred. If the RERR packet is received, all routes using the broken link are erased from the routing table. In case of the sources, the route discovery procedure is executed again if routes are still needed.

III. MATHEMATICAL ANALYSIS FOR ENERGY EFFICIENCY OF ERROR CONTROL SCHEMES

We focus on the MAC layer protocols in sensor networks, and the hop-by-hop error control strategy is discussed. The analysis is based on Mica2 sensor node [9] with ATmega128L processor [10] and CC1000 radio module [11].

ARQ scheme This paper applies stop-and-wait ARQ to sensor networks due to the low reporting rate of the sensor nodes. First, the expression of energy efficiency of ARQ without retransmission strategy is derived. Energy consumption of a sensor node for communication in one hop can be given by: $E_{ARQ} = E_{ARQ} + E_{ARQ}$ –(4)

Where E_x^{trans} is the energy consumed by the node for transmitting the packet , E_x^{re} is the energy consumed by the node for receiving the packet and they can be written as:

$E_{ARQ}^{tran} = E_{DATA}^{tran} + E_{ACK}^{re} =$
$I_{tr}V_{radio}l_{DATA}T_{tr}+I_{re}V_{radio}l_{ACK}T_{tr}$ -(5)

$E_{ARQ}^{re} = E_{DATA}^{re} + E_{ACK}^{tran} =$
$I_{re}V_{radio}l_{DATA}T_{tr}+I_{tr}V_{radio}l_{ACK}T_{tr}$ -(6)

Where I_{tr}, I_{re}, V_{radio} are the transmit urrent, receive current and the supply voltage for CC1000, and$T_{tr}= 1/ R_{radio}$ is the time consumed to transmit 1 bit by CC1000. And DATA-ACK handshake of stop-and-wait protocol is used.
For Mica2 nodes, which are implemented with noncoherent FSK modulation scheme, the bit error rate of this scheme is given by [16], [13]

$P_b = \frac{1}{2} e^{\frac{-E_b}{2N_0}}, \frac{E_b}{N_0} = \gamma \frac{B_N}{R_{radio}}$ -(7)

Where γ is the received SNR, B_N is the noise bandwidth, and *Rradio* is the data rate. Using the bit error rate p_b , the PER for ARQ can be derived as follows:
$PER_{ARQ} = 1-(1-p_b)^{l_{DATA}+l_{ACK}}$ -(8)
Where $l_{DATA} = \alpha + l_{payload}$ is the packet size of DATA, $l_{payload}$ is the length of payload, α is sum of header (MHR) length and
Frames check sequence (FCS) size, as shown in Fig. 1. l_{ACK}. *Is* the packet length of ACK. Energy efficiency of ARQ without retransmission strategy can hence be given as:

$\eta = \frac{E_{ARQ}^{effi}}{E_{ARQ}}(1-PER_{ARQ})=$

$\frac{(I_{tr}+I_{re})V_{radio}l_{payload}T_{tr}}{(I_{tr}+I_{re})V_{radio}(l_{DATA}+l_{ACK})T_{tr}}(1-PER_{ARQ})=$
$\frac{l_{payload}}{l_{DATA}+l_{ACK}}(1-PER_{ARQ})$ -(9)

Where E_x^{effi} is energy consumed by the payload. With the use of ARQ scheme, reliability is achieved by
retransmission if the received data is found to be erroneous. This process continues until the codeword is successfully accepted or the maximum allowable number of retransmission attempts has been exhausted [8].

Next, we assume that maximum allowable number of retransmission attempts is *n* . The energy consumption can be given as

$$E_{ARQ}^{n} = E_{ARQ}\left(1 + PER_{ARQ} + PER_{ARQ}^{2} + \cdots .. + PER_{AQR}^{n-1}\right)$$

-(10)

At this time, the packet acceptance rate of maximum *n* allowed retransmission attempts *n r* is calculated by:

$$r_n = \left(1 - PER_{ARQ}\right) + PER_{ARQ}\left(1 - PER_{ARQ}\right) + \cdots + PER_{ARQ}^{n-1}\left(1 - PER_{ARQ}\right)$$

-(11)

Therefore, energy efficiency can be calculated by:

$$\eta_n = \frac{E_{ARQ}^{effi}}{E_{ARQ}^{n}} r_n = E_{ARQ}^{effi} \frac{\left(1 - PER_{RAQ}\right) + \cdots + PER_{ARQ}^{n-1}\left(1 - PER_{ARQ}\right)}{E_{ARQ}\left(1 + PER_{ARQ} + \cdots + PER_{ARQ}^{n-1}\right)} = \frac{E_{ARQ}^{effi}}{E_{ARQ}}\left(1 - PER_{ARQ}\right)$$

-(12)

We find clearly that the result of equation (9) is the same as (12). Now we can conclude that from a statistical point of view the energy efficiency of ARQ technique is independent of retransmission attempts and is unchangeable with the number of retransmission. The energy efficiency just correlates with the packet size and the communication distance between transmitter and receiver

B. FEC scheme

Energy consumption of FEC can be given as:

$$E_{FCE} = E_{FEC}^{tran} + E_{FEC}^{re} + E_{dec} \quad \text{-(13)}$$

where encoding energy is considered to be negligibly small [7] and E_{dec} is the decoding energy. For a BCH codẹ*n*,*k*,*ṭ*, E_{dec} can be calculated by [16]:

$$E_{dec} = I_{proc}V_{proc}(2nt + 2t^2)3\left\lceil\frac{m}{8}\right\rceil t_{cycle}$$

-(14)

Where I_{proc} is the current for processor,V_{proc} is the supply voltage, t_{cycle} is one cycle duration of processor and *m*□log$_2$ *ṇ*1 [13]. And the expression for the energy efficiency of FEC defined as:

$$\eta = \frac{E_{FEC}^{effi}}{E_{FEC}}\left(1 - PER_{FEC}\right) = \frac{(I_{tr} + I_{re})V_{radio}(k - \alpha)T_{tr}}{(I_{tr} + I_{re})V_{radio}nT_{tr} + E_{dec}}\left(1 - PER_{FEC}\right)$$

-(15)

Where

$PER_{FEC} = 1 - \sum_{i=0}^{t}\binom{n}{i} p_b^i (1 - p_b)^{n+\alpha-i}$ is the packet error rate for FEC. (15) is a bounded function with 0≤ŋ≤1 and its values vary along the error correcting capability *t* which is always an integer. A discrete function with limited values has a maximum. Hence the energy efficiency of FEC can achieve a maximum and the FEC scheme with the largest energy efficiency is the optimum FEC scheme which is based on length of the packet and distance between communication pairs. For error correcting capability *t* of the optimum FEC, there is a tradeoff between the energy throughput $ŋ_e$ and the packet acceptance rate *r*. The enhancing of error correcting capability *t* brings on the increasing of packet acceptance rate *r* but decreasing of energy throughput $ŋ_e$

IV.A. Performance Evaluation

The objective of our simulation is to demonstrate the increased network lifetime by choosing the right path. The proposed protocol was validated using our own network simulator written in C. Some simulations are conducted with different traffic patterns and the network topology. The network topology is created by randomly placing 100 sensor nodes in the area of 100 by 100 meters, while the traffic pattern is changed using different sizes of an event message. Since the simulation results show similar performance in terms of the increased network lifetime, we provide one example of our simulations, as shown in Fig. 1(c). It is assumed that there are only ten possible paths for simulation purposes. One path that is shaded represents the one from the MTE routing protocol, which selects the shortest path in this case. However, our protocol finds a path in a different way. The available node energy is also concerned in our protocol.

Our assumptions:

- There are 100 nodes: 10 by 10 nodes
- There are paths *p*1 through *pn* (n=10)
- Initial node energy: I (5mJ)
- r: distance between nodes and r is fixed as 10m

A right path will be chosen among the discovered paths by taking into account their available energy. Since there are 10 different paths, the average value is calculated over the paths. The path selection algorithm selects every path once for each cycle so that all the discovered paths can be used evenly. In this case, one cycle is assumed to consist of 10

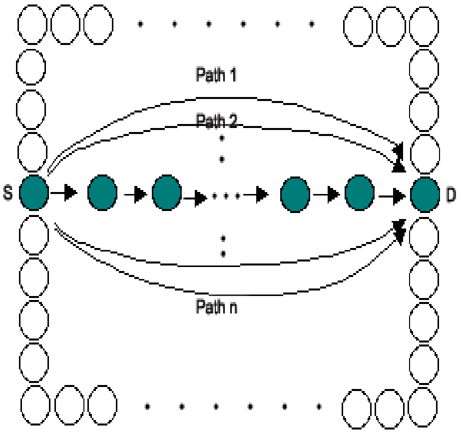


Figure 1(c). Simulation Model

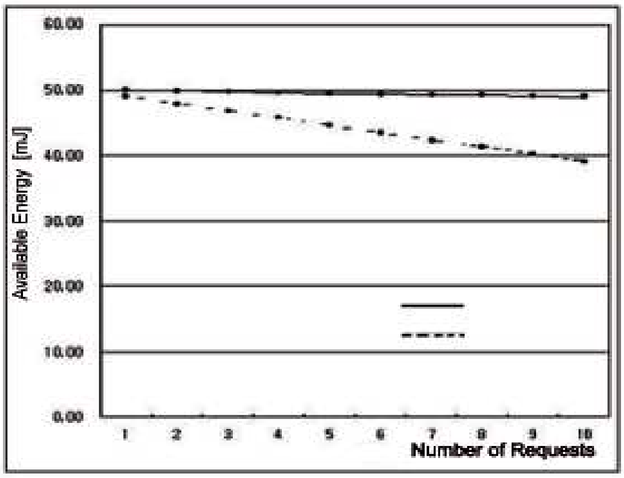
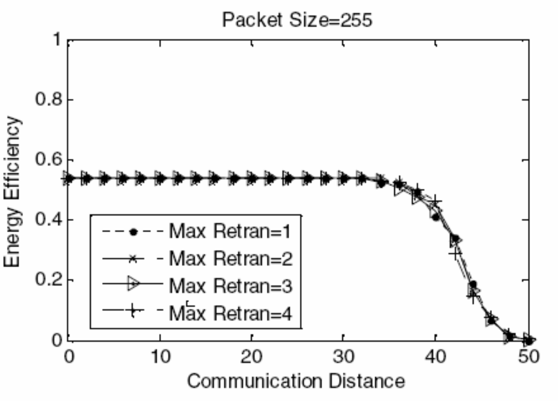


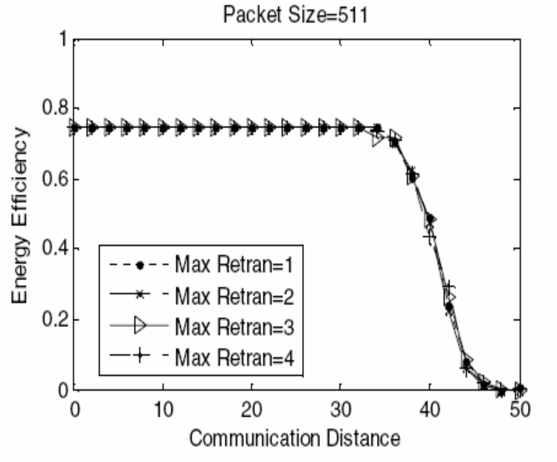
Figure 1(d). Comparison of MTE and our Protocol

rounds, and one round corresponds to each route request from the source. Therefore, we take the average to figure out the energy that is left and available on the network. In Fig. 1(d), it is shown that the available energy in our protocol slowly decreases as the number of route request increases, while the MTE routing protocol decreases sharply. In summary, our routing protocol is more efficient than the MTE routing protocol in terms of energy, because the larger the available energy means the longer the network lifetime. Our path selection algorithm enables to use all the discovered paths evenly so that the energy consumption may be distributed.

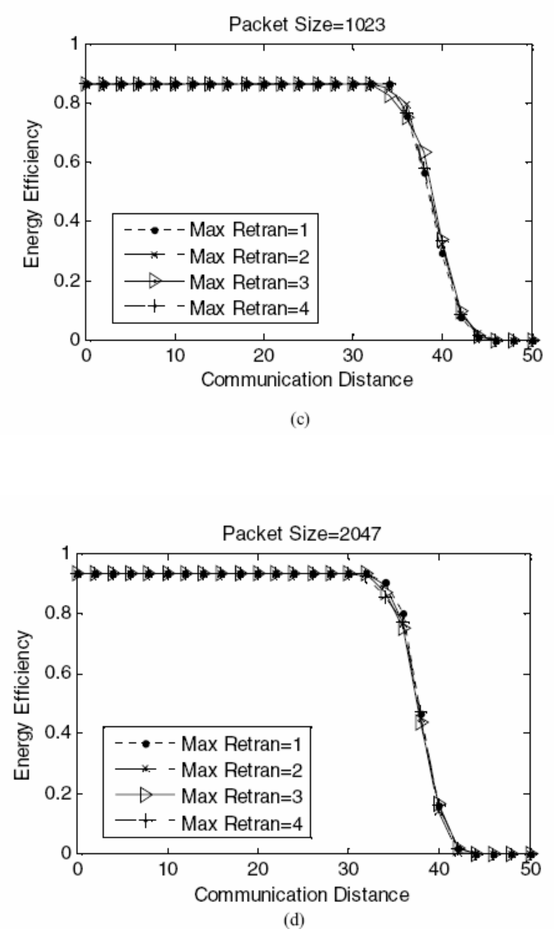
IV.B. V In this section, first, we verify that energy efficiency of ARQ technique is independent of retransmission attempts and is unchangeable with the number of retransmission. Then, the optimum FEC scheme is presented by simulation in different packet sizes and communication distances. The interval of the distances in simulation is 2 meter because of the location error in wireless sensor networks. Finally, we compare energy efficiency of ARQ with energy efficiency of optimum FEC The cases where ARQ outperforms FEC and where FEC is more energy efficient than ARQ are analyzed. For Mica2 node, the values in [16], [9], [10], [11], [14] and [15] are used. For ARQ scheme, Fig.2 (a), (b), (c) and (d) illustrate energy efficiency of ARQ with different maximum allowable number of retransmission attempts which are 1, 2, 3 and 4 respectively in various packet sizes. It is obvious that energy efficiency of ARQ with different maximum allowable number of retransmission attempts is almost the same in a certain communication distance and packet size which coincides with the theoretical analysis.In Fig. 3, error correcting capability *t* of the optimum FEC scheme is shown as a function of the communication distance between the transmitter and receiver. The error correcting capability *t* of the optimum FEC scheme is small for lower distances. *t* increases with the communication distance especially when the distance is larger than 36 meter. Moreover, the packets with bigger length require larger *t* compared with smaller ones



(a)



(b)



(c)

(d)

Figure 2. Energy efficiency of ARQ with different maximum allowable number of retransmission attempts.

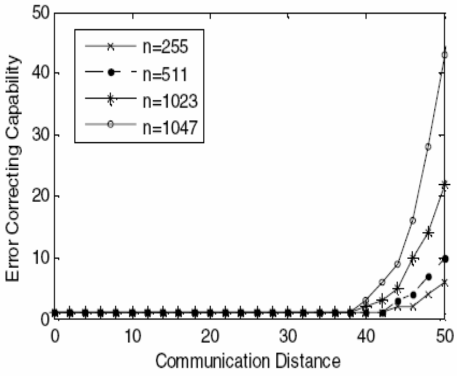
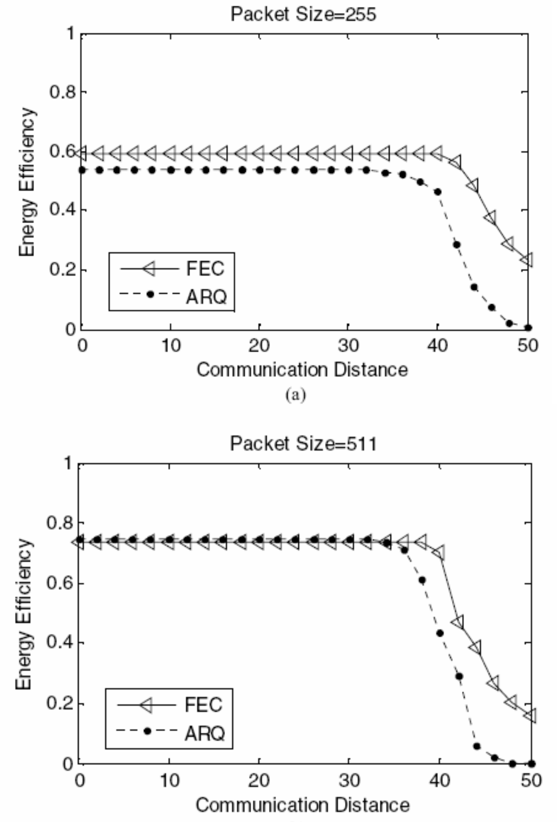


Figure 3. Error correcting capability of optimum FEC scheme

. In Fig. 4, the energy efficiency of ARQ and optimum FEC scheme for different packet sizes are illustrated as a function of the communication distance in one hop. As shown in Fig. 4, for both ARQ and optimum FEC, energy efficiency has little change and the figure is similar to a straight line when communication distance is short. This is because high communication reliability which can be achieved in these distances leads to stable energy efficiency. The energy efficiency of ARQ and optimum FEC scheme increases with the packet size for lower distances. This is mainly because of increscent energy consumed of payload in both ARQ and FEC. And energy efficiency of ARQ strategy increases faster than that of the optimum FEC scheme in this figure owing to the heightening of the decoding energy of FEC. The optimum FEC scheme performs better than ARQ when the packet size is small because ACK of the overhead in ARQ consumes more energy than the decoding energy of BCH code. However, theARQ strategy is more energy efficient when the packet size islarge, because decoding energy of BCH code increases with thepacket size but meanwhile the energy expenditure of ACK in ARQ does not change.



(a)

(b)

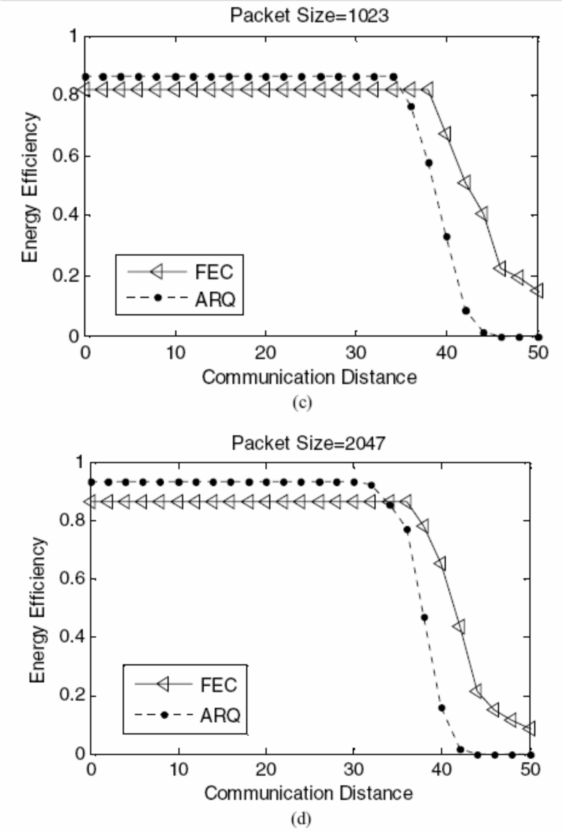


Figure 4 Energy efficiency of ARQ and optimum FEC scheme for different packet sizes and communication distance.As the communication distance between transmitter andreceiver rises, the energy efficiency of ARQ and the optimumFEC scheme descends. And energy efficiency of ARQ strategy decreases faster than that of the optimum FEC scheme. It is clear from (1), (2), (7) that a higher distance results in a higherSNR but a lower bit error rate and FEC schemes have BCHcode to protect the packet from some of the errors. Therefore, the optimum FEC strategy outperforms ARQ for larger distance.

V. Conclusion

In this paper, we propose a path selection algorithm with energy efficiency for wireless sensor networks. The wireless sensor network has more constraints than other wireless networks. The energy efficiency is one of the most important issues in wireless sensor network. By simulation, we have found out that the energy in our protocol is dissipated less than the other energy-aware routing protocols. Energy efficiency of ARQ technique is independent of retransmission attempts and is unchangeable with the number of retransmission. And there is an optimum FEC scheme with the maximal energy efficiency for a target communication distance and packet size. Moreover, ARQ is compared with FEC in terms of energy efficiency based on different communication distances and packet lengths.

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