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Energy Consumption with Fountain Codes and Clustering in Wireless Sensor Networks: Survey & Analysis

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ABSTRACT

Energy is the most important and crucial issue in the wireless sensor networks since the entire sensor nodes are battery powered devices. As a result, energy efficiency and prolonging network lifetime are a challenge. In order to increase the lifetime of the battery-based sensing nodes, it is essential to minimize the consumed energy in the sensing process .With this objective, specific erasure codes called fountain codes are introduced. Fountain codes' performances can be further improved if they are merged with the strategy of grouping sensor nodes into clusters. In order to reach the energy minimization and network lifetime prolonging, the first step, is to completely know the sources of energy consumption. In this paper, sources of energy consumption with various techniques used have been studied and investigated. Furthermore, a survey has been provided for the energy consumption model by using these two techniques.

Keywords: Wireless sensor networks; Fountain codes; Overflow; Clustering algorithms; Energy consumption

1. Introduction

In recent years, wireless sensor networks (WSNs) have gained worldwide attention due to the advances they made in the field of wireless communications, information technologies and electronics. WSNs are the spatially distributed sensors to monitor, detect and collect different events. The fields of applications of this technology are varied such as: military applications (localization soldiers and equipment, intrusion detection), environmental monitoring (signaling forest fires, flood detection systems, collection of agricultural data), medical applications (control of medical equipment, patient monitoring) and the environment intelligent (smart home, interactive games, and positioning vehicles logistics, intrusion detection and monitoring industrial installations)[1]. Given their small size, the sensors usually have limited and non-replaceable energy resources [2, 3]. This is why energy is often the most valuable asset of a sensor network test because it directly affects the lifetime of the sensor, so the entire network. Researches in WSNs are well oriented to this important issue and tried to find a tradeoff between link reliability and energy consumption with limited resources.

Fountain codes are attractive for WSNs because of their rateless property. Indeed, the source can generate limitless encoded packets until it doesn't receive an acknowledgment from the receiver. As a result, if the feedback cannot be transmitted as soon as possible to the source, it will not stop this emission. As WSN mostly relies on multi-hop transmissions, the source still transmitting useless packets creating a specific overhead defined as overflow leading to important energy consumption. One useful technique for reducing the impact of this drawback in terms of energy consumption is the clustering which explores the tradeoff between energy transmission and routing strategy.

Recently, few surveys of clustering methods for WSNs have been presented. These surveys mainly aim at outlining some characters of clustering and summarizing some popular clustering advantages and objectives.

The main contributions of our work can be summarized as follows.

- We give a detailed analysis of energy model. The research presented in this manuscript aims at investigating a comprehensive review of the merge of the two techniques used and their capability to reduce the impact of the overflow.

The remainder of this paper is organized as follows: section 2 provides an overview of fountain code's principle, its encoding and the decoding processes. Section 3 outlines the clustering strategy in the WSNs. In section 4, we systematically analyze and compare the energy model of two different techniques used in the wireless sensor networks. Finally, Section 5 summarizes and concludes this paper.

2. Fountain Codes

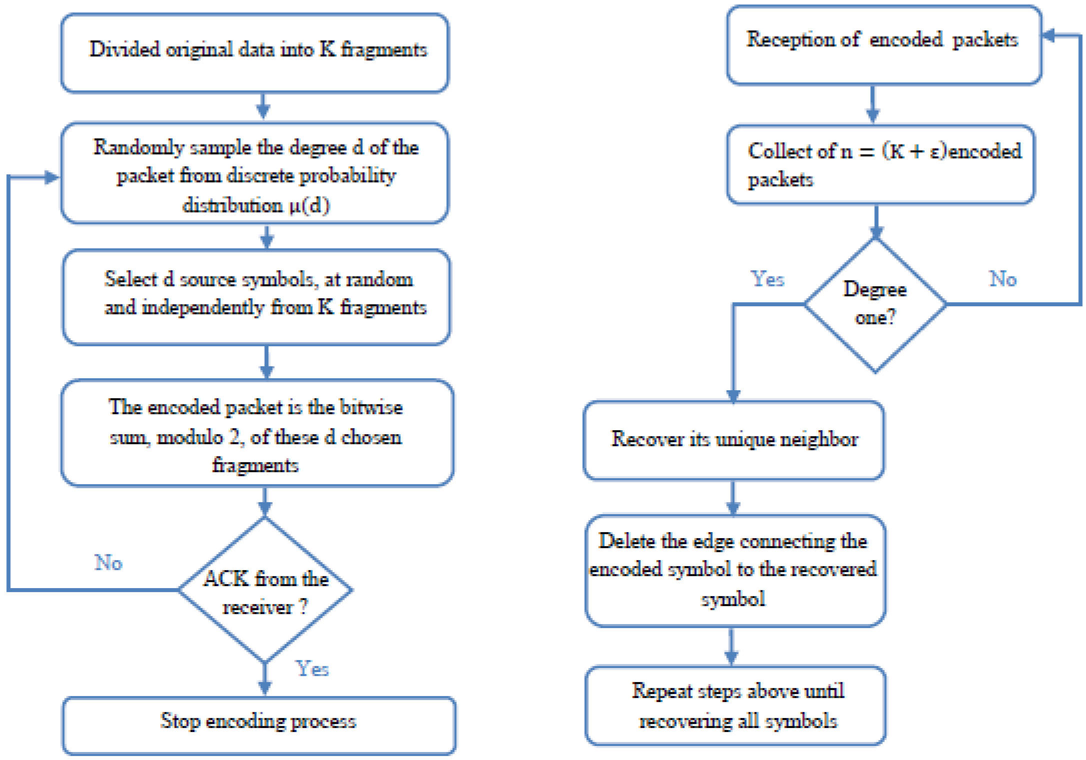
Fountain codes are rateless codes as the source can generate potentially limitless encoding packets from a set of K input symbols. Besides, this type of erasure code has a variety of advantages and features. The most important are its independence of transmission channel. So the encoded packets are adapted to any channel types [4]. The global acknowledgement is the second most important feature of fountain code in comparison with other protocols such as Automatic Repeat reQuest (ARQ) where each data packets needs an acknowledgement (Ack) packet. In the case of error retransmission is made only for the last sent packet, thus, greatly minimizes the number of transmissions, the use of the feedback channel and subsequently the energy consumption [5]. A reliable decoding algorithm for a fountain code is one which can recover the original K input symbols from any set of m output symbols. The decoding cost is the expected number of arithmetic operations sufficient to recover the K input symbols. Desirable properties for a fountain code are an overhead Ɛ close to 1. We well describe briefly Luby Transform (LT) code's principle:

1.1. LT Encoding

In 2002, Luby has published the first type of practical fountain codes, Luby Transform (LT) [6]. This type of codes is very attractive for its low encoding complexity. The source information is divided into K fragments. For each packet, randomly sample the degree *d* of the packet from discrete probability distribution μ and then the *d* fragments chosen from the K original ones are XORed to construct the encoded packet. This coding process is repeated until the reception of an acknowledgement from the receiver. The choice of packet's degree is the main objective of Robust distribution. In fact, the Robust Soliton Distribution RSD [7] is the central and the most important set up in the design of fountain code. The encoding process can be summarized in the figure.1a

1.2. LT Decoding

An efficient decoding algorithm for fountain code must be simple and should allow the recovery of K input symbols. Luby applied to its LT code, Belief Propagation (BP) decoding. It offers a better decoding complexity at the decoding overhead. The decoding proceeds iteratively using Belief propagation (BP) algorithm [**8**] in order to recuperate the source information as shown in figure.1b. Indeed, the above iterative decoding process will come to an end if there are no recovered message symbols or if no encoded symbols of degree one are present in the decoding process. If the decoding process ends without recovering all encoded packet symbols, then the decoder is said to have failed. Otherwise, decoding is successful.



(a) (b)

Fig1. LT code processes. (a) LT encoding flowchart; (b) LT decoding flowchart

As wireless sensor network mostly relies on multi-hop transmissions, the feedback from the receiver to the source, in order to stop the packets' generation, is the main flaw and the important obstacle for the roll-out of fountain code. In fact, during the period of Ack's transmission, the source still transmitting useless packet, creating a specific overhead defined as overflow and leading to an over consumption as it is shown in the figure 2, the dotted lines present the useless packets generated. In spite of the huge advantages of fountain codes and their features, the important obstacle of the roll-out of the fountain codes in a WSN is the cost of acknowledgement. One useful technique for reducing the energy consumption is the clustering technique which explores the tradeoff between energy transmission and routing strategy [9, 4].

We will present in the section below an overview of clustering strategy and an analysis of energy consumption.

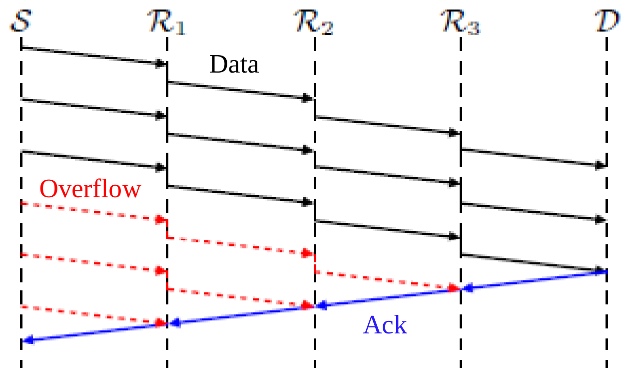


Fig.2. Overflow with multi-hop transmission with fountain codes

3. Clustering Strategy

The clustering of sensor nodes is an effective technique for achieving multi-hop communication by partitioning the network's nodes in a set of meaningful sub classes or groups called clusters. Clustering facilitates distribution of control over the network. Each cluster has a cluster head (CH) which acts as a coordinator [10, 11] as it is represented in the figure 3.

This coordinator gathers the data sent by its respective member nodes and then transmits it to the sink directly or through other cluster heads. Because CHs often transmit data over longer distances, they lose more energy if compared to member nodes. As a result the CH must have a specific performance in term of energy and processing' capabilities. Besides achieving energy efficiency, clustering reduces network contention and packet collisions, leading to a better network throughput under high load [12].

Several algorithms have been proposed by researchers for formation of cluster and election of cluster head. Most of these algorithms consider a performance factor for election of cluster head; these performance factors may be an identification number, connectivity, mobility, battery power.

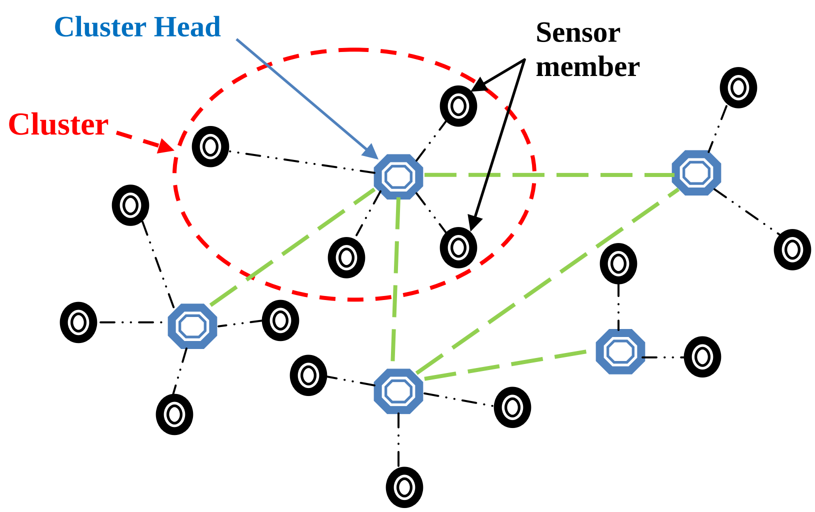


Fig.3. Network's architecture using clustering

4. Energy Consumption Model

The energy consumption of Transceiver comes from multiple operations, including: transmission, reception, decoding, and idle state. By studying the energy consumption issues of node components in different component states , this section presents a general energy model of the processor module, communication module and sensing module of WSN nodes, and then investigates established the node energy model by using the fountain codes and clustering

$$E_{node} = E_{TX} + E_{RX} + E_{dec} + E_{idle} \quad (1)$$

The total energy consumption for a single node can be estimated by the sum of the different components of the application. Thus, E_{TX}, E_{RX}, E_{dec} and E_{idle} are respectively the energy consumed every time the transceiver is transmitting, receiving, decoding or in an idle state.

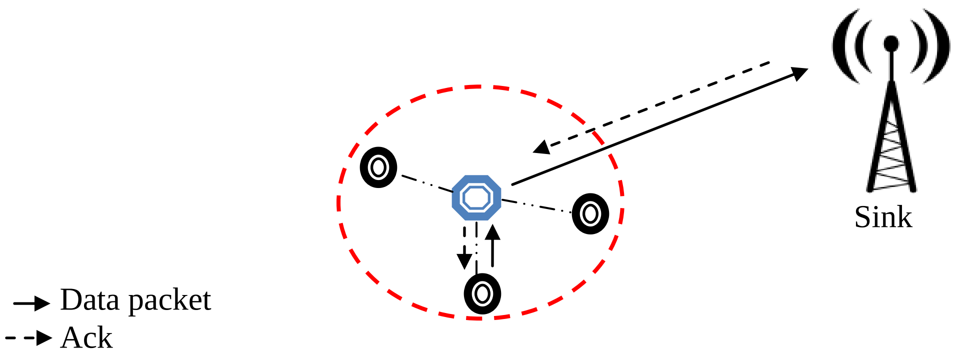


Fig.4. Network's scenario using clustering and fountain codes

The first step involves analyzing the behavior and characteristics of different sensor node. Systematic behavior analysis of a sensor node is extremely important to identify different operations in the system. We analyze two popular sensor nodes, the Cluster head behavior and a wireless sensor member designs in the different operational states.

3.1. Cluster Head Behavior

Cluster head CH takes charge of data fusion within the cluster range, also exchanges the relevant information with other cluster heads, and finally transmits the data to a sink node. In our approach, the CH takes into account the data acknowledgement as it is presented in the figure 5. Indeed, it estimates the incoming data and if it has received enough encoded packet, it transmits an Ack to the source to stop the packets' generation. The use of clustering and CH's estimation reduces extremely the overflow's effect. So the Ack packet reaches the source as soon as possible due to the direct relation between the CH and the source [13].

3.2. Sensor Behavior

Sensor members transmit the encoded data to their associated cluster head and wait for the reception of an Ack from CH.

The general expression of energy consumed by node u per unit of time due to the different transmissions inside the WSN can therefore be written as in [14]:

$$E_{fount} = E^{S}_{fount} + E^{D}_{fount} \tag{2}$$

According to Figure 4, the source is the node member and the destinations are both the cluster head and the sink. As a result, the expression (2) can be more detailed:

$$E_{fount} = E^{S}_{fount} + E^{CH}_{fount} + E^{\text{sink}}_{fount} \tag{3}$$

The total energy consumed at the source is [15, 16]:

$$E^{S}_{fount} = \frac{N_{SN}}{\gamma_{Ack}} \cdot \left\{ \frac{E^{Data}_{TX}}{\gamma_{Ack}} .((K+\varepsilon-1).\gamma_{Ack}+1) + E^{Ack}_{RX} \right\} + \sum_{i=1}^{N_{SN}} E^{i}_{idle} \tag{4}$$

γ_{Data} and γ_{Ack} are respectively the probabilities of success of data transmission and Ack packets. ε is the encoding and decoding cost known as the overhead.
At the cluster head and as it is explained in [17, 16], the total energy consumption can be expressed as:

$$E^{CH}_{fount} = (\frac{N_{SN}}{N_{CH}} - 1). \left[\left\{ (K+\varepsilon-1).\frac{E^{Data}_{RX}}{\gamma_{Data}} + E^{Ack}_{TX} \right\} + l_{Data}.E_{Aggr} \right] + E^{CH}_{idle} \tag{5}$$

N_{SN} is the number of sensor node and N_{CH} is the number of cluster head .Then in average $\frac{N_{SN}}{N_{CH}}$ nodes are per cluster (one cluster head and $\frac{N_{SN}}{N_{CH}} - 1$ non cluster head nodes). Each cluster head aggregates l_{Data} information from its sensor member. As a result, $l_{Data} . E_{Aggr}$ is the energy required to perform the length l_{Data} of data aggregation in a round in order to reduce energy consumption [18]. The energy expanded at the sink to transmit and receive data is given by the equation (6):

$$E^{\text{sink}}_{fount} = N_{CH} \cdot \left\{ \frac{(K+\varepsilon-1)}{\gamma_{Ack}} .E^{Data}_{RX} + E^{Ack}_{TX} \right\} + l_{Data}.E_{dec} + E^{\text{sink}}_{idle} \tag{6}$$

In the illustration of equation (6), the destination receives $(K+\varepsilon-1)$ data packets from the N_{CH} cluster head. Destination transmits N_{CH} Ack in response to the $(K+\varepsilon-1)$ data packets transmitted from the CH, so only one Ack for each cluster head. E_{dec} is the energy consumed to decode a data bit in a BP decoding attempt.

Based on the expression of equation (2), the total energy consumption of nodes is calculated as the sum of the energies consumed by different and individual nodes, which can be expressed as:

$$E_{fount} = \frac{(K+\varepsilon-1)}{\gamma_{Ack}.\gamma_{Data}}.\left\{N_{SN}.E_{TX}^{Data} + E_{RX}^{Data}((\frac{N_{SN}}{N_{CH}}-1).\gamma_{Ack} + N_{CH})\right\}$$
$$+\frac{1}{\gamma_{Ack}}.(N_{CH}.E_{TX}^{Ack} + N_{SN}.E_{RX}^{Ack}) \qquad (7)$$
$$+l_{Data}.((\frac{N_{SN}}{N_{CH}}-1).E_{Aggr} + E_{dec}) + \sum E_{idle}$$

When the destination receives enough packets (about$K+\varepsilon-1$) in order to decode properly the information, it sends a single packet to acknowledge the reception of K fragments. The number of acknowledgment packet is reduced from K to 1 compared to the case of ARQ [19, 20]. The ARQ protocols are classified as Stop and Wait protocols where the sender sends the encoded packets and waits for an acknowledgement before sending the following encoded packet. If for any reason, the Ack is never received, the sender time out and retransmits the data packet.

$$E_{ARQ} = E_{ARQ}^{S} + E_{ARQ}^{D} \qquad (8)$$

The total energy consumption of the ARQ protocol [22] is calculated as the sum of the energies consumed by the individual nodes, and expressed by the expression of the equation (7):

$$E_{ARQ} = \frac{K}{\gamma_{Ack}}.\left\{\frac{N_{SN}}{N_{CH}}.\frac{1}{\gamma_{Data}}.E_{data} + (N_{CH}+1).E_{Ack}\right\} + E_{idle}^{S/D} \qquad (9)$$

E_{data} and E_{Ack} are respectively the energy consumed every time the node is transmitting and receiving data packet and Ack. These two values are expressed as follow:

$$E_{data} = E_{TX}^{Data} + \gamma_{Data}.E_{RX}^{Data}$$
(10)

$$E_{Ack} = E_{TX}^{Ack} + \gamma_{Ack}.E_{RX}^{Ack}$$
(11)

In the illustration of the equation (9), the destination receives $\frac{K}{\gamma_{Ack}}$ times the data packets from the source and transmits $\frac{K}{\gamma_{Ack}}$ number of Ack as response to the first $\frac{K}{\gamma_{Ack}}$ data packets transmitted by the source. It is clear that ARQ error control mechanisms incur significant additional retransmission cost and overhead in case of errors. Indeed, the Ack packet is performed for all K fragments whereas with fountain code, the Ack is transmitted only for the last packet sent.

ARQ protocol is simple to be implemented and it does not need a treatment in the intermediate nodes. On the other hand, the use of the feedback channel leads to a collision and basically to a waste of energy consumption. Therefore, this approach is much more consuming in terms of energy.

In order to avoid overloading of the feedback channel (with retransmissions and acknowledgments) and subsequently reduce energy consumed, the use of fountain codes in order to encode data before transmission and an approach of election and grouping according nodes is much more efficient

Conclusion

Energy is one of the most important issues and challenge in the wireless sensor networks. There are two typical data maining process that support to reduce energy consumption of WSN; fountain codes and clustering. One of the primary goals of clustering is to limit the energy consumed by electing a CH which generally serves like a leader for its cluster, performing intra cluster transmission arrangement, data sending.…

In this paper, we present, the basic concept of fountain codes features, purposes, the clustering concept, and then models of energy consumption are considered. Fountain codes, based on collaborative clustering schemes, limit the energy consumption and consequently, optimize the performance of the network.

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