FRDF: Framework for Reliable Data Fusion to Leverage Communication Performance in Sensor Network

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Abstract. Data fusion technique in wireless sensor network assists in enhancing the data quality in wireless sensor network. Unfortunately, it does it at the cost of energy and uncertainty of data forwarding. We have reviewed various existing data fusion schemes and found that the studies claim to have increase in throughput by using supportability of multipath, but very fewer studies have emphasized on reliable data fusion, considering assurity of data forwarding to destination. Therefore, we introduce a model called as Framework for Reliable Data Fusion in wireless sensor network in order to address these problems. The paper discusses about three core algorithm i.e. algorithm for (i) distributed tree construction, (ii) reliable data fusion, and (iii) data forwarding reliability. The outcome of the proposed system is found to excel superior with respect to energy saving and enhance communication performance in comparison to existing techniques.

Keywords: Data fusion · Fuser node · Reliability · Energy efficiency · Wireless sensor network

1 Introduction

Wireless sensor network is one of the most pivotal areas of research under wireless network due to its beneficial factors as well as continued unsolved problems associated with it. Such forms of the network consist of three types of nodes member node, cluster head, and sink node [1]. Member node extracts the raw environmental data, uses TDMA scheduling, and forwards the data to cluster head, which in turn accumulates multiple data from the member nodes.

This process is just called as data collection. However, during data collection, it is quite possible that a cluster head collects redundant data and forward it to sink, in which case it may result in additional control overhead. In order to solve this problem, a cluster head perform filtering of the redundant data using statistical computation, to forward the unique data to the base station [2]. This principle is called as data fusion and plays a significant role in enhancing the data quality in wireless sensor network [3]. However, the biggest challenging problem is uncertainty associated with the exact time of event generation, which leads to higher degree of energy variance that further

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significant reduces the lifetime of the wireless sensor network. As the wireless sensor network works on the principle of radio-energy model [4], it can be said that enhanced communication performance demands more amount of energy. Hence, data fusion is also closely linked with energy problems. However, to some extent the available techniques of energy efficient routing can enhance the performance of data fusion, but still the problem lies in few facts e.g. (i) inability to identify and repair an intermittent links over increasing rounds of iteration, (ii) there is assurity that fused data will be reaching its destination (it could be any other node in multihop or base station in single hop). Although, there are many existing systems that has focused on energy efficient data fusion, but still they do not ensure reliability. Here reliability is the term, which relates to forwarding of the fused data from distributed data fusion to the destination node. Reliability factor becomes more important, when compared to energy saving, especially with respect to time-critical applications in wireless sensor network. There are various applications, which need sensitive messages to reach the destination at any cost, and with high degree of reliability. Hence, this paper presents one such novel technique that assists in enhancing the reliability of the data fusion in wireless sensor network.

The rest of the paper is organized as follows. The background of the proposed study is discussed in Sect. 1.1 along with the contribution of some of the existing research work. Section 1.2 briefly describes the problems statement after reviewing the existing system, the proposed solution contribution is described in Sect. 1.3. Section 2 presents elaborate discussions of the algorithms implemented to ensure energy efficiency and reliability during data fusion over large-scale wireless sensor network and are followed by the result discussion in Sect. 3. Finally, the Sect. 4 is used to conclude our paper.

1.1 Background

This section discusses about the existing techniques that have been discussed most recently in the area of data fusion in wireless sensor network. Our prior study [5, 6] has already reviewed some of the standard techniques of data fusion. We have also presented a model called as EEDF (Energy Efficient Data Fusion) most recently that focuses on incorporating virtual multipath data fusion in wireless sensor network [7]. Zhu et al. [8] recently carried out the problem of reliable data transmission. Considering up and downlink communication path, the author has presented a model that can perform an energy-efficient data fusion in wireless sensor network. Liu et al. [9] have presented a study to emphasize the need of energy efficiency during data fusion modelling. Li et al. [10] who have used back propagation algorithm in order to enhance the convergence performance of fuser node in wireless sensor network carried out studies towards optimization of data fusion. Jorio et al. [11] have presented a fusion technique using geographic routing approach along with hierarchical techniques. Ma et al. [12] who have introduced a clustering technique along with a unique fusion model using reputation factor also addressed the problem of reliability in data fusion. Dingcheng et al. [13] have presented a technique that uses Bayesian approach to perform data fusion. The study outcome was testified using standard dataset using squared error. Zhou et al. [14] have introduced a technique that uses Dempster-Shafer evidence theory in order to enhance the performance of multi-sensor data fusion. Reliability problem in data fusion was also addressed in the work carried out by Peng et al. [15] where the outcome was found to posses reduced delay. Wang and Dong [16] have adopted unscented Kalman filter to leverage the performance of Multiscale data fusion in wireless sensor network using both simulation and experimental approach. Bangash et al. [17] have introduced a technique that ensures reliable routing over body sensor network considering constraint data packets. Testified with and without relay nodes, the study outcome was found to posse's better delivery ratio. Luo and Li [18] have presented a technique that ensures the better fault tolerance performance for distributed fusion in wireless sensor network. The technique performs quantization of its sensed data considering multiple network constraint. The study outcome was tested with ROC curves. Tan et al. [19] have presented a study to show an impact of data fusion over coverage and connectivity in wireless sensor network. Using explicit scaling laws, the technique performs data fusion. Yuan et al. [20] have developed a technique of data fusion where threshold plays an important role. The author uses local and global thresholding scheme for performing threshold-based data fusion computation.

Hence, it can be seen that there are various techniques for addressing data fusion problems where such study has contributed to new guidelines in enhancing performance, but at the same time, the existing studies are also shrouded with many pitfalls. The next section discusses about the problems being identified in the existing system.

1.2 The Problem

The problems explored after reviewing the existing system are as follows:

- Majority of the study was focused on energy efficiency and very less number of studies has actually addressed the reliability problems in data fusion.
- Less focus on distributed data fusion techniques leads to non-exploration of the problems associated with large-scale data fusion.
- Few studies are dedicated towards identification of intermittent links caused due to ineffective design of data fusion in wireless sensor network and to autonomously address it.
- Studies pertaining to energy efficient data aggregation, routing, and spontaneous routing updates are quite less.

The problem statement of the proposed study is –"*It is a computationally challenging task to develop a framework that can formulate the condition of reliability in data fusion along with assurity to forward the fused data to sink in wireless sensor network*." The next part of the study presents the contribution.

1.3 The Proposed Solution

The proposed system introduces a model called as Framework for Reliable Data Fusion (FRDF) in wireless sensor network. The prime target of this modelling is to incorporate some conditional feature during data fusion in order to ensure that fused packets once relayed must reach the base station irrespective of the presence of intermittent or broken links over a multiple hop communication system. The main emphasis is laid on to, developing a technique that can estimate the minimum amount of energy, which is required to achieve 100% reliable data fusion operation in wireless sensor network. The research approach will be purely analytical. The architecture of proposed system is shown in Fig. 1

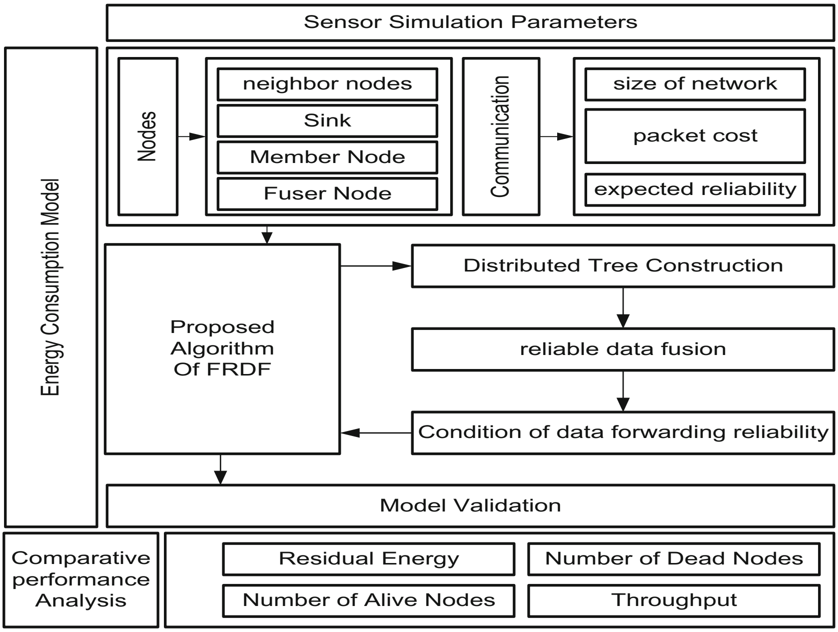

Fig. 1. Proposed architecture of FRDF

The contributions of proposed system are as follows:

- A simple graph theory is used for implementing a novel design of data fusion in order to model the routing strategy from nodes to sink.
- A new parameter called as cost of data fusion is designed where cost means the accurate amount of information contained in fused data after performing data fusion. It also relates to amount of information being received by the node and is affected by the tree structure of data fusion.

- An algorithm is developed that can compute the extent of data reliability after the fusion is performed considering amount of fused data received at base station to total number of data being disseminated from the parent node (or cluster head).
- A novel condition for data fusion reliability is introduced that considers that a sensor with maximized cost will also require maximized data forwarding reliability in order to achieve a targeted reliability score as well as minimization of the cumulative energy consumption during transmission.

The next section elaborates the above-mentioned contribution of FRDF with respect to algorithm design implementation.

2 Algorithm Implementation

The proposed system implements three different algorithms in order to ensure energy efficient and incorporate reliability feature in data fusion over large-scale wireless sensor network. Current section is used to discuss the algorithms involved in the design of proposed system.

2.1 Algorithm for Distributed Tree Construction

This algorithm is mainly an extension to our prior EEDF [7] by strengthening the contraction of the distributed tree in order to assort good number of routes. All the computation is carried out with respect to hops right from each node to base station. We consider that a base station broadcast a particular message called as DTC_{msg} to all the nodes (Line-1). The design of the DTC_{msg} is kept simple by keeping only 2 fields in its data frame i.e. (i) identity I of the node and (ii) hop distance d, which will be used by the DTC_{msg} to pass. For simpler computation, we initiate the hop distance d with value 1 at the position of the base station. Only the nodes x which receives the beacon DTC_{msg} (Line-2) performs validation if the hop distance value is less than hop distance value that it has stored (Line-4). The base station S also forwards a query for network size, cost of packet, and anticipated reliability. Cost of packet will mean size of packet in our fusion model and reliability factor can be computed by packet cost towards sink divided by total packet cost. For true condition, the sensor updates the value of next hop i.e. ($x + 1$) with the value of the field ID of DTC_{msg} (Line-5). At the same, it also updates the value of hop distance d of $\mathrm{DTC_{msg}}$. The sensor also performs relaying of the DTCmsg (Line-1–8). However, identification of false condition will mean that the sensor has already acknowledged the $\mathrm{DTC_{msg}}$ for which reason it has to reject the $\mathrm{DTC_{msg}}$.

Algorithm for Distributed Tree Construction

Input: S (Sink), DTC_{msg} (Distributed Tree Construction message), η (size of network), pkt_{wt} (packet cost), α_{pkt} (expected reliability)
Output: Distributed Tree Construction
Start
1. $S \rightarrow$broadcast($DTC_{msg, d}$)
2. $x \leftarrow$received(DTC_{msg})
3. $S \rightarrow$query(η, pkt_{wt}, α_{pkt})
4. if $d(x) > d(DTC_{msg})$ and flag(x)
5. then, $(x+1) \leftarrow ID(DTC_{msg})$
6. $d_x \leftarrow d(DTC_{msg})+1$
7. $ID(DTC_{msg}) \leftarrow IDx$
8. $d(DTC_{msg}) \leftarrow d_x$
9. $flag_x \leftarrow$false
10. End
11. else
12. x reject(DTC_{msg})
13. End
End

2.2 Algorithm for Reliable Data Fusion

This algorithm is initiated only after the sensors started detected any significant event and results in selection of reliable data fuser node. All the active sensors participate in the selection of best fuser node in this algorithm. The proposed concept assumes that cluster head usually resides near to the base station. However, as we implement random distribution which may result in farthest distance too (from sink to node). In such case, we select the cluster head on the existing established link (Line-6–7). In this algorithm, initially the sensors are shortlisted based on the event sensing capability of a node i.e. $\eta_{evn.}$ All the monitored node *x* can be considered to be subset of event detected sensors and hence can be referred to be eligible for playing the role of fuser node. In such case, fuser node *x* will announce the identified event in the form of broadcasting. All the neighbor nodes that have received this broadcasted message will perform a computation shown in Line-5–16. The neighboring nodes checks if the distance value of *x* is more than distance value of neighbors, than the broadcasting node *x* can play the role of member node. A member node will perform retransmission of broadcasted message, which are received from neighbor node ω. However, if the distance of *x* is equivalent to distance of neighbor node ω than the neighbor node checks identity of *x* is more than that of neighbor node ω. In such, the broadcasting node will play the role of member node itself. The computation continues until a single node is found to be announced as reliable fuser node. The algorithm allows all the nodes that have sensed the similar event to be acting as member nodes, whose responsibility is to collect the information and then forward it to the fuser node that in turn finally forwards it to the base station. The prime beneficial factor of this algorithm is that the sensors capturing the equivalent events at one node only i.e. reliable fuser node, which consumes less energy, filters more redundancies, and ensures smaller travel period, fuse entire data.

Algorithm for Reliable Data Fusion

Input: η_{evn} (sensors detected an event), ω (neighbor nodes)
Output: x (reliable data fuser node)
Start
1. η_{evn} ← event
2. for each x ε η_{evn}
3. x ← fuserNode
4. x → announce(identifiedEvent)
5. foreach (ωεneighborNode)
6. if d(x)>d(ω) then
7. x ← memberNode
8. end
9. elseif d(x)=d(ω)
10. ID(x)>ID(ω) then
11. x ← memberNode
12. end
13. else
14. x rejects broadcast from ω
15. end
16. end
End

2.3 Algorithm for Condition of Data Forwarding Reliability

The main purpose of this algorithm is to ensure 100% reliability such that the data will be forwarded among the sensors network. In this case, the new fuser node x that has been selected from previous algorithm (Algorithm for reliable data fusion). Then the selected fuser node x transmits a message for establishing route to its next hop represented as (x + 1). After the acknowledgement is received by the next hop (x + 1), it forwards it to all its descendants which significantly assists in updating the distributed tree on other hand. The iteration continues until and unless the search terminates after obtaining base station. In case it does not reach the base station, then it alternatively searches for a sensor, which is already present in an established route. Hence, it can be seen that proposed system has good supportability of multihop communication system during fusion operation in sensor network. We construct a condition of reliability to establish the routes by selecting the superior neighbouring nodes present at each hops. The contraction of condition is carried out in dual stages i.e. (i) after the preliminary event, the sensor with shortest path to base station and (ii) after an event has already occurred, the sensors that are already in an established path. One of the key advantage of this algorithm is that it enhances the fusion points, in order to ensure that data fusion will occur more to generate more reliable data and also will be transmitted with increased reliability. Finally, the outcome of this algorithm is basically a tree that links the reliable data fuser node with the base station. This algorithm also supports higher frequency of updates during routing, and mostly carried out by relay nodes. The relay node forwards messages for updating the hops. The algorithm also checks, if the sensor does have data packets to be forward to more than one branches br_y. In positive case, the sensor waits for a specific period and fuses all the data and then forwards the data to its consecutive hop (x + 1) or else it directly forward it to next hop (x + 1). For every iteration, we identify the need to increase the data reliability by flagging the situation of data delivery. The reliability is increased by ensuring that a transmitting node must wait for pre allocated duration in order to get the acknowledgement of data deliver. In case of failure to receive the acknowledgement, a new receiver node is chosen and the acknowledgement message is reforwarded through that node.

Algorithm for Condition of Data Forwarding Reliability

Input: x(fuser node of current event), y (node receiving msg from current fuser node x), br_y (branches of y node)
Output: Ensuring each node get data to transmit

```
Start
x→msg(x+1)
Iterate
    if y=(x+1) then
        d←0
        y←relay
    end
Until sink node is found
Iterate
    If br_y>1 then
        fuseddata→(x+1)
        if y←relay
            Flag→Reliability need to be increased
        end
    end
    else
        transmit pkt→(x+1)
        if y←Relay
            Flag→Reliability need to be increased
        end
end
Until sensor get data to transmit.
End
```

The prime advantage of proposed system is to construct a reliable path in the form of the tree that can forward unique data to the base station and thus enhance the data fusion process in wireless sensor network. Another advantage is usage of flagging mechanism to identify which are all the consecutive routes that have been failed to be detected. In such case, the failed route is compensated by exploring new consecutive route. The proposed system uses a simple cost computation, which is the amount of

Table 1. Notation used in algorithm design

Notation	Meaning
S	Sink node
DTC_{msg}	Distributed Tree Construction message
X	Node receiving DTC_{msg}
D	Hop distance
H	Size of network
pkt_{wt}	Packet cost
α_{pkt}	Expected reliability
Ω	Neighbor nodes
br_y	Branches of y node
η_{evn}	Sensors detected an event

non-redundant fused data in order to ensure lesser retransmission attempt. It also displays an efficient data fusion reliability model (Table 1).

3 Result Discussion

The result analysis is carried out by simulating 100 sensor nodes across 1200 × 1500 m^2 simulation area. The nodes are initialized with 0.5 J of energy with packet length of 20000 bytes. The outcome of proposed Framework for Reliable Data Fusion (FRDF) is compared with our prior model EEDF [7] and LEACH [21] with respect to residual energy, alive nodes, throughput, and dead nodes.

Figure 2 highlights the comparative analysis of the residual energy which shows that sustenance of LEACH [21] is restricted to extremely less simulation rounds, which is exceeded by prior EEDF [7] model. EEDF formulates better link selection criteria based on stabilized energy, which cannot be found in LEACH. Moreover, EEDF also supports multihop resulting with less occurrences of error thereby saving significant amount of energy as compared to LEACH. However, proposed FRDF further optimizes EEDF by ensuring better route and data reliability conditions. Our present model has a mechanism of flagging the unestablished links (i.e. link created between two nodes with less energy) along with identification of failed link discovery, which adds quite value to prior structure of data fusion. Another enhancement in our proposed approach is the inclusion of cost factor, which significantly reduces the redundancies thereby further reducing transmittance energy consumption. The inclusion of new reliability factor is dependent on the data cost of sink to total, which can be obtained during the routing operation and does not require any extra computational steps. Hence, FRDF does not require much computational steps and hence enough residual energy is found to revive the sensors for more rounds.

Figures 3 and 4 shows the graphical outcome of alive and dead nodes respectively. The plotted values in both the figures can be founded to be symmetric to each other with respect to number of alive and dead nodes. Proposed FRDF uses scope-based flooding process, which is not only used for route discovery but also for updating routing information. This process simultaneously enables all the neighbouring nodes to

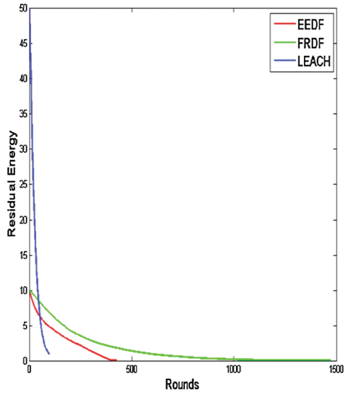

Fig. 2. Comparative analysis of residual energy

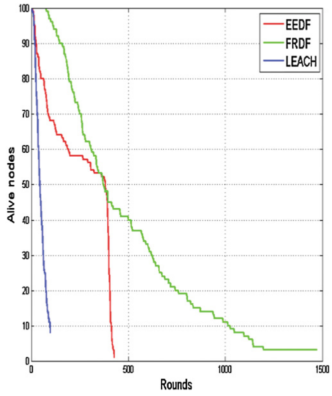

Fig. 3. Comparative analysis of alive nodes

establish and update the root along the path at the same time causing significant reduction in energy due to the effort exerted by other nodes to get the update. Moreover, reduction of retransmission positively assists in further increasing the longevity of network lifetime.

As per the observation made in Fig. 4 with respect to dead nodes, FRDF tends to be quite predictable and does not exhibit linearity as LEACH or uncertainty associated similarly to that of EEDF. The reason behind LEACH behaving linearly is due to excessive energy drainage during routing and clustering owing to inefficient selection process or cluster head.

Moreover, LEACH does not support multihop. The limitation of EEDF is basically due to the uncertainty associated with the construction of routes based on topology and current channel condition without including any technique to identify/discover/rectify the broken link, if any and Moreover, the best link selection is based on energy level only. However, whereas in proposed FRDF, there are multiple factors and condition that leverage the fuser node selection process. The route formation is based on three different forms of routing message, which gives more comprehensive information about the nodes and links using distributed tree construction process. Therefore, the death of the nodes occurs very slowly and uniformly in FRDF, when compared to LEACH and EEDF.

Figure 5 highlights the throughput accomplished by the proposed system FRDF with comparison to existing techniques LEACH and EEDF. EEDF provides a better throughput than LEACH, as it uses a mechanism of virtual multipath propagation to increases the data delivery in multifold, however, EEDF does not have the capability to identify the reliable routes and hence leads to sudden drop in throughput. Thus, it indirectly affects the network longevity by using more transmittance energy during path failure. This problem is completely solved by our proposed system FRDF that not only identify and formulate the condition for data reliability, but also rectifies the problems of intermittent links. Hence, throughput of our proposed system FRDF significantly outperforms our prior models LEACH and EEDF.

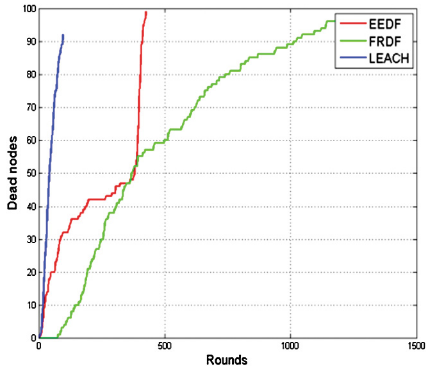

Fig. 4. Comparative analysis of dead nodes

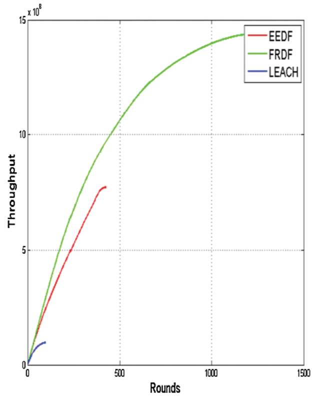

Fig. 5. Comparative analysis of throughput

4 Conclusion

Data fusion plays a very important role in increasing the data quality by filtering significant amount of redundant data during the data dissemination process in wireless sensor network. We have reviewed some of the recently implemented and relevant techniques that is known to enhance the performance of the data fusion process in wireless sensor network. We find that all the existing techniques are more or less focusing on accomplishing the energy efficiency, but at the same time unable to ensure, if the fused data could reach the destination node over uncertainty of the intermittent nodes in wireless sensor network. Hence, reliability is the less focused technique in this perspective. This paper presents a framework that can enhance the data fusion technique using distributed tree configuration over multihop communication system. The technique has the capability to identify the intermittent links and can perform data transmission through alternative routes to ensure that fused data is perfectly delivered. The outcome of the study was implemented in Matlab and compared with our prior model and existing LEACH algorithm to find that proposed system outperforms both in terms of energy efficiency and escalated communication performance at the same time in wireless sensor network. Our future study will be focusing on further optimizing the process of data fusion in large-scale wireless sensor network.

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