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Error Control Technique for Loss Recovery in Cluster Based Mobile Wireless Sensor Networks

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Abstract: Existing loss recovery techniques are developed mainly for static Wireless Sensor Networks (WSNs) which cannot be directly applied for mobile sensors networks. Developing a loss recovery and error control technique for Mobile Wireless Sensor Networks (MWSNs) is a challenging one due to the mobility of nodes. It involves huge amount of overheads in terms of additional bits added and hence consume more energy. In this study an error control technique for loss recovery is proposed for cluster based MWSN. Each Cluster Head (CH) or Forwarder Node (FN) encodes the data and transmits to the selected forwarder node which in turn will decode and retransmit it to the sink. Based on the channel error probability, Low Density Parity Check (LDPC) code and multipath encoding techniques are adaptively applied. Simulation results show that the proposed technique reduces the packet drop and energy consumption.

Key words: Error control, loss recovery, cluster, WSN, MWSN, energy

INTRODUCTION

Wireless Sensor Network (WSN) is a group of wireless sensors deployed to monitor different environmental conditions (e.g., forest fire, air pollutant concentration and mobile objects) in a collaborative way without relying on any underlying infrastructure support. Due to low manufacturing cost and quick deployment wireless sensors are widely adopted to meet the specific application requirements. One of the applications of WSN is intrusion detection that has gained lot of popularity because of its diverse implementation, e.g., wireless sensors deployed in an ad hoc manner to monitor military environment (Raza *et al.*, 2015). WSNs are used in many application domains which include personal applications such as home automation, business applications such as sales tracking, industrial applications such as architectural and control and military applications such as enemy target monitoring and tracking (Rassam *et al.*, 2013).

For WSN, error detection and correction services are usually provided by communication protocols at the data link and the transport layers. Generally, the error detection scheme requires certain amount of overheads in terms of additional bits which are added to the total transmitted data. These additional bits are used by the receiver to check for error on the sequence of data that might occur during the transmission (Roshanzadeh and Saqaeeyan, 2012). Packet delivery ratio, reporting rate, energy consumption, throughput, bandwidth delay product, resource utilization and packet size are the parameters affecting error recovery (Liu *et al.*, 1997).

Developing a loss recovery and error correction technique for mobile sensor networks is a challenging one. Existing loss recovery techniques are developed mainly for static WSNs, hence, cannot be directly applied to mobile sensor networks. The commonly used error control techniques in WSN are:

- Forward Error Correction (FEC)
- Low-Density Parity-Check (LDPC) coding
- Joint source coding
- Network coding
- Automatic Repeat Request (ARQ) wherein only error detection capability is provided and no attempt to correct any packets received in error is made instead it is requested that the packets received with error, be retransmitted

FEC codes employs error correcting codes to combat bit errors (due to channel imperfections) by adding redundancy to information packets before they are

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transmitted. This redundancy is used by the receiver to detect and correct errors. There exist various FEC codes that are optimized for specific packet sizes, channel conditions and reliability requirements such as linear block codes (BCH and Reed-Solomon (RS) codes) and convolutional codes. LDPC codes are a class of recently rediscovered highly efficient linear block codes which can provide performance very close to the channel capacity.

A cluster based routing protocol with mobility prediction for MWSN has been proposed (Paranjape and Sutaone, 2013). The selection of Forwarder Node (FN) is mainly based on the delivery utility (Xiong *et al*., 2010) and link stability. The main task of forwarder node is to collect information from the CH and transmit it to sink node via. other Chs. Hence, as an extension to Paranjape and Sutaone (2013), this study proposes error control technique for loss recovery in cluster based mobile wireless sensor networks.

Literature review: Babiker *et al*. (2011) have proposed an efficient energy Adaptive Hybrid Error Correction Technique (AHECT). AHECT adaptively changes error technique from pure retransmission (ARQ) in a low BER case to a hybrid technique with variable encoding rates (ARQ & FEC) in a high BER cases. An adaptation algorithm depends on a pre-calculated Packet Acceptance Rate (PAR) look-up table, current BER, packet size and error correction technique used is proposed. Based on this adaptation algorithm a periodically 3 bit feedback is added to the acknowledgment packet to state which error correction technique is suitable for the current channel conditions and distance.

Kleinschmidt and Borelli (2009) have proposed an adaptive error control strategies for wireless sensor networks using informational value of messages. The informational value is based on sensors coverage area. Important packets are protected by more powerful error control schemes than less important packets. BCH codes and retransmission schemes were analyzed using OQPSK modulation in Rayleigh fading channels.

Xu *et al*. (2007) have proposed an effective coding scheme that exploits the tradeoff between redundant data transmission and encoding/decoding complexity. Two key design parameters of the proposed scheme, the degree of repair packets and the number of repair packets are derived to achieve a high data recovery probability with minimum coding redundancy and computation overhead. Furthermore, the proposed scheme is leveraged under recoverable and permanent failure models for proactive transmission. Accordingly, the expected probability of a destination obtaining all data packets is analyzed.

Marinkovic and Popovici (2009) have proposed one relay network and show that network coding along with redundancy can be used as a very efficient error recovery mechanism that greatly improves network reliability at very low computational and hardware cost. Thus, network coding can be an interesting method for reliability improvement in medical systems such as Wireless Body Area Networks (WBAN).

Qaisar and Radha (2007) have proposed an Optimal Progressive Error Recovery Algorithm (OPERA) over WSNs. Under OPERA, individual intermediate sensors which are relaying data toward the base station, partially and optimally channel-decode the incoming packets while employing a progressive decrease in parity bits as data reaches the final destination. OPERA requires significantly lesser processing than would be required for complete decoding or full decoding/encoding at the sensor nodes and OPERA significantly reduces the total number of transmissions when compared to optimal end-to-end channel coding schemes. We use iteratively de-codable LDPC codes for this purpose. OPERA not only provides a partial processing framework but also an algorithm to optimally map the decoding iterations over the multi hop network

MATERIALS AND METHODS

Error Control Technique for Loss Recovery (ECTLR) Overview: In this study, we propose to apply an error control technique at each CH and forwarder nodes in order to ensure correctness of data and perform loss recovery. Each CH applies encoding using LDPC codes (Qaisar and Radha, 2007) or the scheme by Xu *et al*. (2007) depending on the channel error probability before forwarding the data to the next CH. When the error probability is low, LDPC codes (Qaisar and Radha, 2007) are applied. When the error probability is high, then the multipath encoding scheme (Xu *et al*., 2007) is applied.

When the receiving CH or selected forwarder node receives the encoded packet, it performs decoding and checks for the correctness of data. Then based on the decoded packets, it again performs encoding and forward towards the next CH. This process continues until the encoded packets reach the sink (Fig. 1).

Clustering architecture: Following the deployment of sensor nodes in the network, the sink broadcasts the

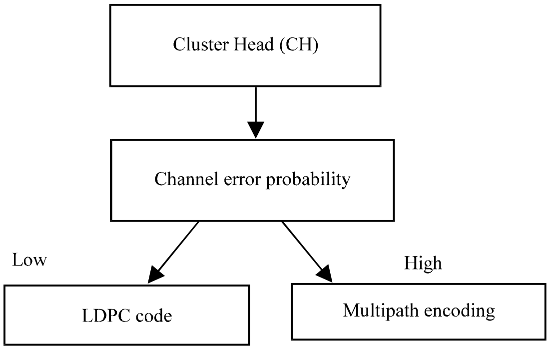

Fig. 1: Proposed methodology for ECTLR

Node Information Request packet (N_INFO) to all the Nodes (N_i). N_INFO includes the fields node ID, Sequence Number (SeqNo), Node Speed (SN) and Link Stability (LS). N_i upon receiving the N_INFO packet updates the field with its SN_i and Link Stability LS_{ij} values. Then, it transmits the N_INFO packets to the sink. Sink chooses the nodes with maximum link stability and minimum speed as the Cluster Head (CH_i). N_i which gets selected as CH_i broadcasts a hello message to the neighboring nodes within the transmission range. The neighboring nodes upon receiving hello message becomes the members of the respective CH_i. Each cluster member with the cluster is aware of all the members contained within the cluster and each time the clusters are formed, the cluster information gets updated in the sink. These steps are repeated until all the clusters are formed (Fig. 2).

Algorithm 1; ECLRT algorithm:

Notations	Meaning
$P(n_i)$	Channel error Probability for node n_i
Ep_{th}	Threshold for Error probability
SINR	Signal to Interference Noise Ratio
P_T	Transmission Power level per bit
P_A	Ambient noise Power
P_{int}	Interference Power of any concurrent transmissions

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CH receives data from $n_i$
CH estimates $P(n_i)$ using Eq. 1:
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$$P(n_i) = Q(\sqrt{2}.(SINR(n_i))) \tag{1}$$

$$\text{where } Q(a) = \frac{1}{2\pi}\int e^{(-u/2)}du \tag{2}$$

$$\text{and } SINR = \frac{P_T}{P_A + \sum P_{int}} \tag{3}$$

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CH checks $P(n_i)$
If $P(n_i) \le EP_{th}$, then
    LDPC coding algorithm is applied
Else
    Encoding algorithm is applied
End if
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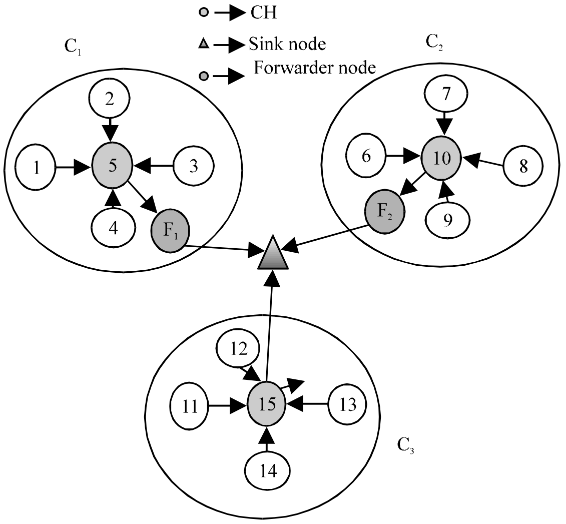

Fig. 2: Clustering architecture of MWSN

In this algorithm, if the error probability is less than or equal to EP_{th}, then LDPC coding is applied and if it is above EP_{th}, the encoding scheme (Xu *et al*., 2007) is applied. In our simulation experiments, EP_{th} is considered to be 0.5.

LDPC codes: Low Density Parity Check (LDPC) codes are systematic block codes which are being used extensively due to high level performance. The LDPC algorithm repeatedly calculates the distribution of variables in graph-based models and is referred by different names/variations including Sum Product Algorithm (SPA), Belief Propagation Algorithm (BPA) or more generally, Message Passing Algorithm (MPA).

In this study, the LDPC code is used when $P(n_i) \le EP_{th}$. Since, in WSN, the resource at every node including the source, destination and forwarding nodes are limited, code with lesser transmissions would be effective. Due to reduced error probability in the data packet using the parity levels to minimize the transmissions in the forwarding nodes would be appropriate.

Algorithm 1; LDPC coding algorithm:

Notations	Meaning
DP	Data Packet
CH_S	Source CH
FN_i	Forwarding Node
CH_D	Destination CH

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$CH_S$ adds the parity bits to DP using LDPC codes
CH send the encoded DP to FN
While DP not reaches $CH_D$
Do
    $FN_i$ safely removes the parity levels from the encoded data
    $FN_i$ forwards the data packet to the $Fn_{i+1}$ which performs parity level changes accordingly
End while
```

The resulting data packet at the forwarding node is still capable of being decoded, since, the LDPC parity check matrix is same throughout the network.

Encoding scheme: The encoding scheme uses the proactive multipath transmission to increase the packet recovery rate. For the recovery of the lost data packets, the encoded packets are used. Basically, the encoded packets are the repair packets generated by the source node. Each repair packets have a degree which is generated by the source node. Initially, all the repair packets have the equal degree.

Algorithm 3; Encoding algorithm:

1. When a repair packet is being transmitted to the destination, the source node includes the degree of the data packet in it
2. Since, the overhead involved is equal to the degree of repair packet, a pseudo random generator is used by the source and the destination to reduce the overhead
3. The source sends the seed for the random generator and the data packet ID along with the repair packet
4. On receiving the repair packet, based on the data packet ID included, the destination identifies the data packet to be encoded
5. Then based on the seed and the data packet ID, the repair packet regenerates the IDs of the data packet
6. Next, decoding is performed in two phases
7. In the initial phase, the destination node classifies the received packets into three types: unprocessed data packets, processed data packets and repair packets
8. Then the destination node picks a data packet from the unprocessed set and scans the repair packet set
9. If the ID of the data packet is detected in the repair packet while scanning then the data packet is moved to the processed set and the degree of the repair packet is reduced by one
10. Similarly, all data packets are scanned and moved to processed set
11. If there still exist any repair packet that has still not been decoded, then the phase two is used
12. In phase two, the destination node gathers all the repair packets that have not been decoded
13. Then every repair packet is handled as in a procedure of solving equation sets with several variables
14. The obtained solution will be the recovery of the lost packets
15. This process is continued till all the repair packets have been decoded

RESULTS AND DISCUSSION

Simulation settings: The proposed Error Control Technique for Loss Recovery (ECTLR) is evaluated through NS-2 Simulation. The performance of ECTLR is compared with the traditional LDPC technique (Qaisar and Radha, 2007). The simulation settings are given in Table 1. The performance of the two techniques is evaluated in terms of packet delivery ratio, packet drop and energy consumption.

Results and analysis

Varying the number of nodes: In the initial experiment, the number of nodes is varied from 50-200 with node speed 5 m/sec.

Figure 3 shows the delivery ratio measured for ECTLR and LDPC when the nodes are varied. The nodes are increased from 50-200 and as we can see from Fig. 3, the delivery ratio of ECTLR decreases from 0.40- 0.21, the delivery ratio of LDPC decreases from 0.30-0.16. Hence, the delivery ratio of ECTLR is 16% of higher when compared to LDPC.

Figure 4 shows the drop measured for ECTLR and LDPC when the nodes are varied. The nodes are increased from 50-200 and we can see from Fig. 4, the drop of ECTLR increases from 4339-19378, the drop of LDPC increases from 7480-23682. Hence, the drop of ECTLR is 30% of lower when compared to LDPC.

Table 1: Simulation settings

Number of nodes	50, 100, 150 and 200
Area size	1000×1000
Mac	802.11
Radio range	250 m
Simulation time	25 sec
Traffic source	CBR
Packet size	512
Receiving power	0.395
Sending power	0.660
Idle power	0.035
Initial energy	10.0 J
Data sending rate	100 Kb
Speed	5, 10, 15, 20 and 25 m/sec

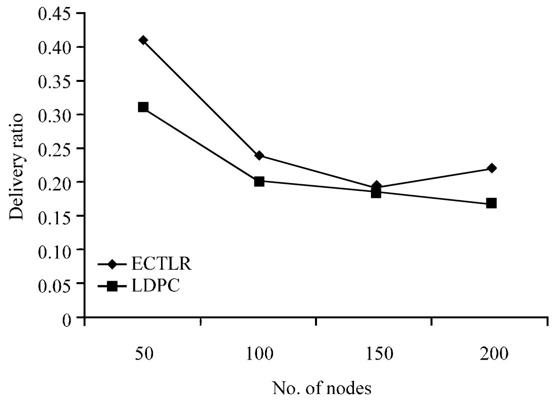

Fig. 3: Nodes vs. delivery ratio

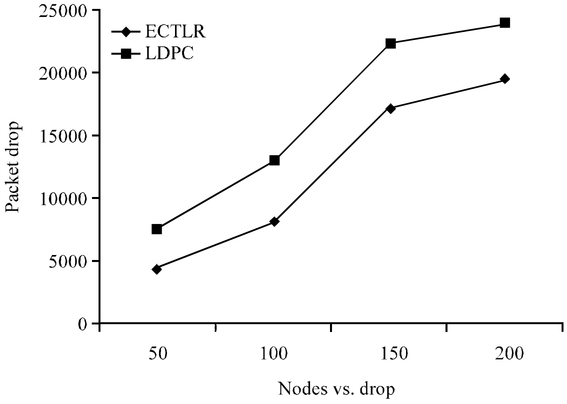

Fig. 4: Nodes vs. drop

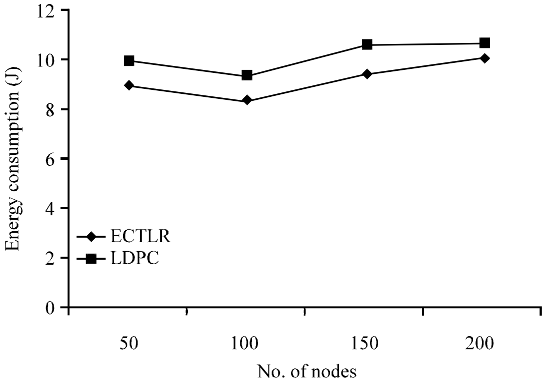

Fig. 5: Nodes vs. energy consumption

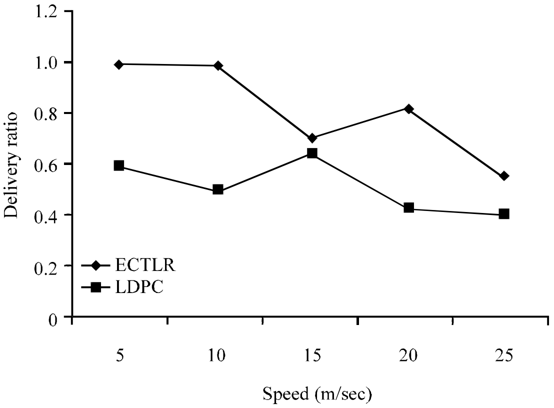

Fig. 6: Speed vs. delivery ratio

Figure 5 shows the energy consumption measured for ECTLR and LDPC when the nodes are varied. The nodes are increased from 50-200 and we can see from Fig. 5, the energy consumption of ECTLR increases from 8.76-9.85, the energy consumption of LDPC increases from 9.75-10.47. Hence, the energy consumption of ECTLR is 9% of lower when compared to LDPC.

Varying the node speed: In second experiment, mobile node's speed is varied from 5-25 m/sec keeping the number of nodes as 100.

Figure 6 shows the delivery ratio measured for ECTLR and LDPC when the speed is varied. The speed is increased from 5-25 m/sec and we can see from Fig. 6 that the delivery ratio of ECTLR decreases from 0.98-0.54, the delivery ratio of LDPC decreases from 0.58-0.39. Hence, the delivery ratio of ECTLR is 35% of higher when compared to LDPC.

Figure 7 shows the drop measured for ECTLR and LDPC when the speed is varied. The speed is increased from 5-25 m/sec and we can see from Fig. 7 that the drop of ECTLR increases from 22-294, the drop of LDPC increases from 370-796. Hence, the drop of ECTLR is 82% of lower when compared to LDPC.

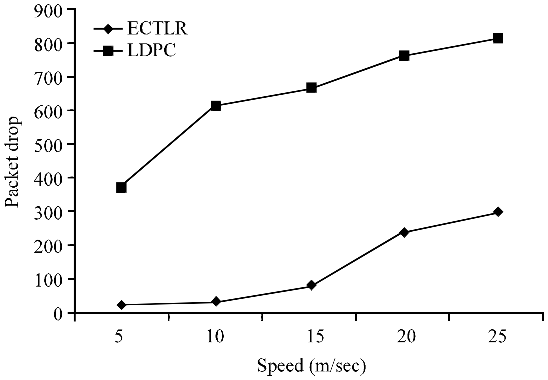

Fig. 7: Speed vs. drop

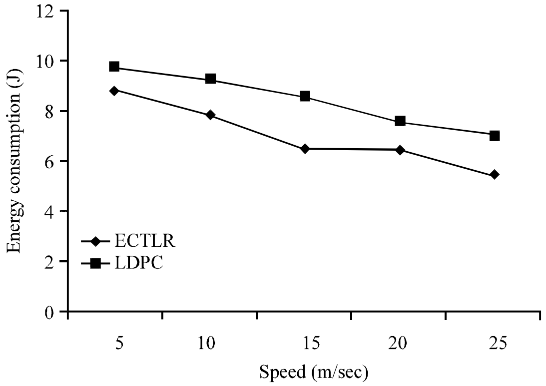

Fig. 8: Speed vs. energy consumption

Figure 8 shows the energy consumption measured for ECTLR and LDPC when the speed is varied. The speed is increased from 5-25 m/sec and we can see from Fig. 8 that the energy consumption of ECTLR decreases from 8.68-5.47, the energy consumption of LDPC decreases from 9.69-6.94. Hence, the energy consumption of ECTLR is 17% of lower when compared to LDPC.

CONCLUSION

In this study, an Error Control Technique for Loss Recovery (ECTLR) has been proposed for cluster based mobile wireless sensor networks. Each Cluster Head (CH) or Forwarder Node (FN), checks the channel probability of the received packets. If the estimated error probability is less then LDPC codes are used otherwise, proactive loss resilient encoding technique is applied. The CH encodes the data and transmits it to the selected FN which in turn will decode and retransmit it to the sink. Simulation results show that the ECTLR reduces the packet drop and energy consumption when compared to the existing technique.

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