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RRDVCR: Real-Time Reliable Data Delivery Based on Virtual Coordinating Routing for Wireless Sensor Networks

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Abstract: Real-time industrial application requires a routing protocol that guarantees data delivery with reliable, efficient and low end-to-end delay. Existing Two-Hop Velocity based Routing (THVR) protocol relates two-hop velocity to end-to-end delay to select the next forwarding node, that has the overhead of exchanging control packets and depleting the available energy in nodes. We propose a Real-Time Reliable Data delivery based on Virtual Coordinates Routing (RRDVCR) algorithm, based on the number of hops to the destination rather than geographic distance. Selection of forwarding node is based on packet progress offered by two-hops, link quality and available energy at the forwarding nodes. All these metric are co-related by dynamic co-relation factor. The proposed protocol uses a selective acknowledgment scheme that results in lower overhead and energy consumption. Simulation results show that there is about 22 and 9.5% decrease in energy consumption compared to SPEED respectively, 16 and 38% increase in packet delivery compared to THVR and SPEED respectively and overhead is reduced by 50%.

Keywords: End-to-End Delay, Link Reliability, Maximum Transmission Count (MTX), Virtual Coordinating Routing, Dynamic Co-relation Factor: $f(rt)$

Introduction

Wireless Sensor Networks has a wide range application namely, intruder tracking, medical care, health diagnosis and fire monitoring (Li *et al*., 2007). Industrial communication community applications demand rigid end-to-end delivery and reliability (Akkaya and Younis, 2005; Yanjun *et al*., 2009) under the constraints of wireless communication.

Real-time QoS guarantees can be differentiated into two classes: Rigid real-time and soft real-time. In rigid real time system, end-to-end delay tolerance is not allowed. The arrival of a packet after its specified end-to-end delay is considered as a fault in the system. On another hand, in soft real time system, a probabilistic guarantee is required and delay is tolerated. Hence, Real-time QoS in WSNs should guarantee deterministic or probabilistic end-to-end delay. In real-time support in WSNs, energy efficiency cannot be ignored as the sensor nodes have a severely limited energy budget. Sensor nodes radio can be in active or sleep state to make it energy efficient, but then the sensor nodes should spend most of their time in a sleep state and in which they are not able to transmit or receive data during that period. These properties do not favor the adoption of sensor networks in rigid realtime data delivery. The MAC layer provides channel access to the next hop while the network layer provides the end-to-end transmission time. The cross-layer design can be used to obtain optimum results (Li *et al*., 2007).

Motivation: Real-time guaranteed data delivery with low end-to-end delay and energy-efficiency is the most demanding requirement in industrial applications of WSNs. The traditional QoS routing protocol based on tree based routing is inefficient for dynamic network topology/asymmetric link characteristics. The geographically based routing achieve maximum packet progress towards the destination within end-to-end delay. However, it considers only geographic distance rather than a number of hops in the expenditure of energy and delay. Shortest-path-first maintains a list of optimal routes between the source and destination satisfying either reliability or timeliness. Therefore, it is required to design a real-time QoS routing protocol that guarantees packet delivery within a deadline and lower energy usage resulting in enhanced lifetime of the network.

Contribution: We have proposed RRDVCR protocol and the contributions are listed as follows:

(i) Optimum path between the source node and the destination node is achieved in terms of the number of hops using virtual coordinates routing. (ii) Introduce a new dynamic weighting factor that analyses packets differently, depending on the remaining time to meet the end-to-end delay. (iii) A QoS parameter Maximum Number of Transmission Count [MTX] indicates link quality between the two nodes. (iv) Simulation performance comparison demonstrates low control overhead and energy consumption of the proposed RRDVCR protocol.

Organization: Paper is structured as follows: Section 2 reviews related work. Section 3 introduces system model, mathematical model and problem definition. The proposed protocol is described in section 4. Simulation parameters are listed in section 5. The simulation results presented in section 6. Conclusions are contained in section 7.

Literature Survey

This section summarizes the state of the research work emphasizing the QoS-aware routing protocols.

Jalel and Yahya (2010) propose Energy-efficient and QoS Aware Multipath Routing Protocol that maximizes lifetime by balancing the energy utilization across multiple nodes; it uses to service differentiation to allow the sensitive packet to reach the destination within the specified delay. However, multipath routing is not suitable because sending packets over multiple paths inevitably incurs significant energy cost.

Li *et al.* (2008) use Two-hop neighborhood information to select the next forwarder node. The packets are routed based on Two-hop velocity and energy utilization. This algorithm reduces packet deadline miss ratio. However, this work enhances the lifetime of the network at the cost of more energy consumption.

Prabh and Abdelzaher (2007) propose Transmission Scheduling Algorithm for Hexagonal Networks. That ensures that bottleneck node does not idle, with implicit clock synchronization to facilitate scheduling. However, the proposed scheduling algorithm works for only certain topology.

Chen *et al.* (2008) use *k*-hop neighbor information for geographic packet routing with potential improvement in routing delay and energy consumption in transmissions. However, as with the increase in the number of hops, it suffers from low Packet Reception Rate (PRR) and high re-transmission cost.

Spohn and Garcia-Luna-Aceves (2004) propose Three-hop Horizon Pruning (THP) to reduce the collision due to broadcasting. The algorithm computes a Two-hop Connected Dominating Set (TCDS) where each node selects the smallest subset of its one-hop neighbors which in-turn use its two-hop neighbors to reach next nodes three hops away. However, it is not feasible to determine link quality between nodes. The drawback is that frequent HELLO messages have to be exchanged to measure the link quality.

Lou and Wu (2002) addressed the problem of determining the minimum number of forwarding nodes, with total dominant pruning and partial dominant pruning. It uses two-hop neighborhood information to reduce redundant transmissions. However, each intermediate node decides whether to rebroadcast the packet based on termination criterion that guarantees delivery. If no such termination criteria exist, then all packets are dropped.

Katia *et al.* (2006) propose Traffic-Adaptive Medium Access protocol (TRAMA) which provide collision-free channel access in Wireless Sensor Networks. It uses a distributed election scheme based on traffic at each node to determine the time slot. Each node switches a low-power, idle state. However, proposed protocol is suited for delivery guarantees and energy efficiency than delay sensitive applications.

The protocols (He *et al*., 2005; Felemban *et al*., 2006; Chipara *et al*., 2006) achieve real-time end-to-end delay requirement by selecting the next forwarding node based on the velocity offered by one-hop neighborhood.

Joseph *et al.* (2004), propose Low-media Access scheme to minimize duty cycle and idle time. However, it does not address packet delivery guarantee and reliable data transmission.

NS-2, (Online), propose ZigBee routing protocol that uses Hierarchical Tree Routing (HTR). It meets the end-to-end delay requirements but it consumes more energy.

The real-time QoS routing protocol for WSNs proposed in (Akkaya and Younis, 2003). It finds least cost paths using extended Dijkstra's shortest path algorithm for both real-time and non-real time requirements during connection establishment. Different paths are chosen for real-time traffic and non-real time traffic. It uses a queuing model to serve both traffic. However, it does not consider asymmetric nature of the channel and the priority based queuing is too complex for resource constrained sensor nodes.

A modified version of AODV protocol is proposed in (Boughanmi and Song, 2008), with prioritized packets based on its urgency. Packets with rigid end-to-end delay requirement are assigned with higher priority and are allowed through critical energy nodes and improve the network lifetime. However, the protocol has higher packet loss ratio.

Geographic Opportunistic Routing (Cheng *et al*., 2014) selects and prioritizes the forwarding node that meets required end-to-end reliability and delay. It is based on one-hop neighborhood information for determining the node position. There is an increase in the control packets resulting in higher energy consumption. Gradient Routing with Two-hop (Quang and Kim, 2012) uses selective acknowledgment scheme to update the neighbor information. However, the protocol does not use link reliability between the nodes while making a routing decision.

Niu *et al.* (2013) propose Reliable Reactive Routing Enhancement [R3E] protocol that uses the biased backup scheme to determine guide path. It improves the packet delivery ratio and reduces the energy utilization. However, construction and maintenance of virtual path during route discovery introduces high overhead.

Two-Hop Velocity based Routing algorithm (THVR) (Yanjun *et al.*, 2009) uses geographic distance to determine the velocity of the packet for given the end-to-end delay requirement for real time data delivery in WSNs. In THVR (Yanjun *et al.*, 2009), each node selects forwarding node based on the location of neighbors and the destination which requires a large number of control packet and energy. Jung *et al.* (2010) propose Multi-hop Information based Real-time Routing which obtains information from only around data forwarding paths resulting in minimum deadline miss ratio with the lower number of message exchange and computation complexity compared to THVR (Yanjun *et al.*, 2009). However, OMLR (Jung *et al.*, 2010) scheme does not use an optimal number of hops to forward the packet to the sink and results in high energy consumption and packet miss ratio.

To meet real-time applications stringent QoS requirements of in terms of latency, delivery ratio and/or jitter, a Cross-Layer based Admission control scheme (CLAP) is designed in (Pinto *et al.*, 2015). In this admission control mechanism, it adopts the technique to estimate packets end-to-end delay and rebroadcast a packet if and only if it will not miss the delay requirement defined by the application, dropping it otherwise.

To achieve reliable and energy efficient transmission in WSNs, The next forwarding node selection is based on the performance of a neighboring node in terms of the rate of packets successful forwarding, queue length, acknowledgment ratio and energy remaining (Feng *et al.*, 2016). Similarly, different aspects such as node duty-cycling, wireless broadcast advantage, unreliable links and power adjustability of a node are taken into account to determine next forwarding node (Han *et al.*, 2015).

To tackle faulty nodes and achieve reliable data delivery in WSNs, a novel trust model is proposed in (Ahmed *et al.*, 2015) which detects and isolates misbehaving and faulty nodes from forwarding task. Similarly, a fuzzy-based trust estimation mechanism is used for node trust estimation and mitigate the effects of security threats in a network and reliable delivery of data (Umar *et al.*, 2017).

To reflect the change in nodes behavior, the combined global and local route update mechanism is incorporated into a hierarchical proactive routing framework to tackle potential routing path problems in WSN (Pradittasnee *et al.*, 2017). To ensure reliable network coverage in low-duty-cycle WSN, Dynamic Switching Based Reliable Flooding (DSRF) framework is proposed (Cheng *et al.*, 2016).

The Reliable data delivery is accomplished achieved through the use of multiple routes and switching of the routes as decided by the Base station (Sarma *et al.*, 2010), QoS-aware and Heterogeneously Clustered Routing (QHCR) protocol use several alternative routing paths from a source to a destination, The selection of alternative paths on the basis of initial energies of the sensing nodes, traffic load and packet delivery ratio (Amjad *et al.*, 2017).

To alleviate the connectivity-hole and energy efficiency problem, in (Xu *et al.*, 2016) author exploits the advantage of clustering and routing and propose a Joint Clustering and Routing (JCR) protocol. The backoff-timer and gradient routing schemes are jointly used in cluster head selection and multi hop routing with low overhead.

System Model and Problem Formulation

Virtual Coordinate Routing for WSNs

The proposed algorithm adopts virtual coordinate routing protocol which enhances packet delivery reliability. All symbols used in this work are given in Table 1. The sink node builds reverse path tree by propagating Advertisement (ADV) packets to collect the data from the sensor nodes, the ADV packet contains variables: *sinkID*, *sourceID*, *residual energy*, *link quality* (*MTX*) *value and height-count*. In each ADV packet, the sink node is set to *height-count* to 0. The *height-count* at the node is the minimum energy oriented and a minimum number of hops to forward the packet from the i^{th} node to the sink. Upon receiving the ADV packet, each node sets its height equal to *height-count* in the packet and increments *height-count* by 1 and rebroadcast the ADV packets to its neighbor. The *height-count* of each node is indicated as N_h. The *height-count* for the sink node is set to 0. The *height count* of the source node and any node i is indicated as h_s and h_i. Figure 1 shows height-count of a node i to sink X, Y, Z respectively.

Reliability Estimation Model

Several methods are introduced to indicate link quality they are: Received Signal Strength (RSS), Link Quality Indicator (LQI) and Expected Transmission Count (ETX). The measurement of RSS, LQI is not accurate because of noise and interfering transmission (Entezami *et al.*, 2014). Hence, they are not considered as a link-quality metric. RSS is a signal-based indicator and it is not related to the received packets.

Table 1: Notations

Symbols	Definition
N_h	Height-count of each node
h_s	Height-count of source node
h_i	Height-count of any node *i* in network
$curP_{suc(i,j)}$	Minimum success probability offered by link
$pl(i,j)$	Minimum success probability rate
$ed_{(i,J)}$	Expected media delay from node *i* to *j*
$T_i(Boff)$	Random back off time
$T_{(i,Data)}$	Transmission delay for sending packet
$T_{(i,Ack)}$	Transmission delay for acknowledgment
$E_{(n,res)}$	Residual energy of forwarding node *i*
$E_{(n,ini)}$	Initial energy of node *i*
$E_{(n,sen)}$	Energy required for sensing event
$E_{(n,rec)}$	Energy required for receiving packet
$E_{(n,res)}$	Energy required for transmitting packet
$N_{(i)}$	Set of one-hop neighbor
S	Source node
Dest	Sink node
$N_{1(i)}$	Set of one-hop neighbor in one-hop area
$N_{2(i)}$	Set of two-hop neighbor of node *i*
$N_{h(i,j)}$	Number of hop between a pair of node *i* and *j*
$N_{h(S,Dest)}$	Number of hop between source and destination
S_p	Expected packet speed towards destination
D_{req}	Required end-to-end delay
$c_{(1,i)}$	Available one-hop forwarder set of node *i*
$c_{(2,i)}$	Available two-hop forwarder set of node *i*
$S_{p((i,j)\to k)}$	Set of two-hop neighbor provide speed
$ve_{(i,j,k)}$	required speed for forwarding packet
β	Weighting factor
rt	Remaining time to satisfy end-to-end delay
$f(rt)$	Co-relation factor
f	Packet size
E_{th}	Threshold energy

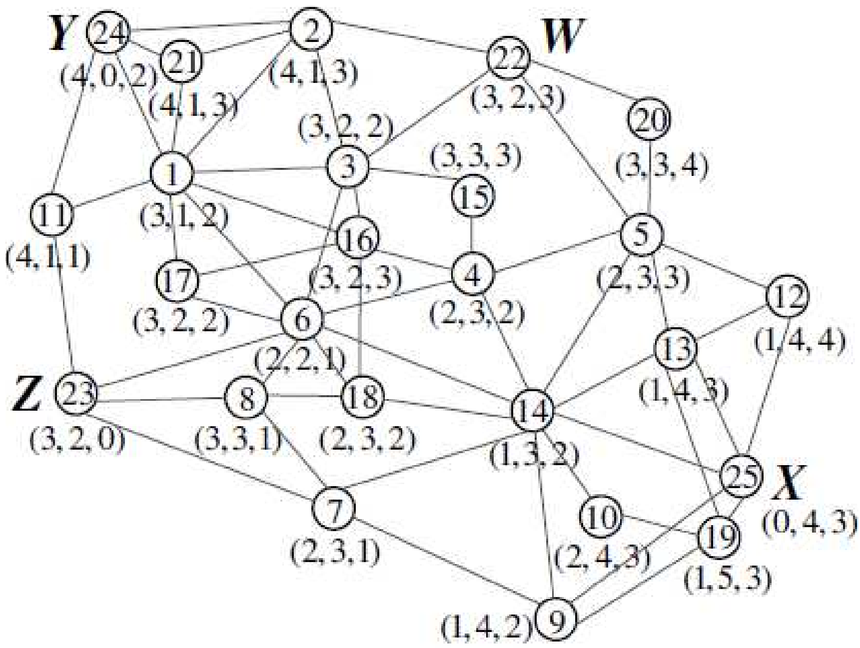

Fig. 1: Illustrate virtual coordinating points for a node which reflect hoplength to sink nodes X ,Y, Z respectively (considering multiple sink)

Therefore, RSS cannot be used as metric to indicate the link-quality. The LQI is another metric to indicate the link-quality, the LQI is a built-in parameter in CC2420 (Lou and Wu, 2002) chip that is used in a most wireless sensor node, LQI uses the average correlation value of RSS for each receiving packets. Expected Transmission Count (ETX) is the predicted value of transmissions that deliver packets successfully over wireless links in a bidirectional manner. The forward delivery ratio d_t is the probability that a packet is received successfully at the receiver. The reverse delivery ratio is calculated based on reception of the acknowledgment packets at the sender. The probability that a packet is sent to the receiver and its acknowledgment is given as:

$$P_{suc} = d_r * d_t. \tag{1}$$

The ETX is the inverse of probability of successful transmissions (Entezami *et al*., 2014), as shown below:

$$ETX = \frac{1}{P_{suc}} = \frac{1}{d_r * d_t}. \tag{2}$$

Although ETX is very efficient, the ETX metric is based on the average behavior of the link ($E[P_{suc}]$), but ETX does not check whether the current success probability ($curP_{suc}$) results in better delivery of the packet. Whenever current success probability ($curP_{suc}$) is less than the maximum number of retransmission allowed by MAC-layer, there is a high probability that transmitted packets are discarded because of increase in a number of re-transmissions. Therefore, it is necessary to take into account of the maximum number of re-transmissions allowed by the MAC layer. The physical layer properties and important in measuring the link quality in wireless networks to improve the performance. This paper defines the new metric called Maximum Transmission Count (MTX). That denotes the required number of transmissions on a link taking into account the maximum number of re-transmissions allowed by the MAC-layer (MaxRetry). Minimum success probability $Pl(i, j)$ offered by link between nodes i and (j) is denoted as:

$$Pl(i,j) = \frac{1}{Max\,Retry}. \tag{3}$$

If current success probability $curP_{suc}(i, j)$ is less than the minimum success probability $Pl(i, j)$ offered by link between nodes i and j, the MTX metric is then defined as:

$$MTX(i,j) = \begin{cases} \dfrac{1}{curP_{suc}(i,j)} \; for & curP_{suc}(i,j) \geq Pl(i,j) \\ \dfrac{1}{Pl(i,j)} \; for & curP_{suc}(i,j) \leq Pl(i,j) \end{cases} \tag{4}$$

The MTX metric indicates that packet transmission is possible whenever the current success probability $curP_{suc}(i, j)$ is more than minimum success probability ($Pl(i, j)$).

Media-Delay Estimation Model

Let T_k be the single hop channel delay of the jth candidate, the channel delay can include the back-off delay and transmission delay of the data packet at the sender. The second part is the candidate coordination delay, which is the time needed for the kth candidate to acknowledge the sender. The single-hop channel delay is defined in Equation 5, where the signal propagation delay is ignored:

$$ed(i,j)Ti_{Boff} + Ti_{Data} + j\left(T_{SIFS} + T_{Ack}\right). \tag{5}$$

where, Ti_{Boff} is random back-off time for the sender to capture the channel, T_{SIFS} is Short Inter Frame Space. Ti_{data} and T_{Ack} are the transmission delays associated with the data packet and ACK respectively.

Energy Model

In WSNs, the energy consumption for the forwarding node includes energy for sensing events, receiving packets, retransmitting the packet of the previous nodes and energy for transmitting locally generated packets and while f is packet size. The residual energy of the forwarding node at a time t is indicated as:

$$E_{(n,res)}(t) = E_{(n,ini)} - E_{(n,sen)}(t) - (E_{(n,rec)}(t) + E_{(n,tr)}(t)) * f \tag{6}$$

The energy consumption at the source node includes energy for sensing events and transmitting packets. The energy dissipation for receiving packet is not included:

$$E_{(0,res)} = E_{(0,ini)} - E_{(0,sen(t))} - (E_{(0,tr(t))} * f. \tag{7}$$

To guarantee the correct functioning of the forwarding node, the remaining energy at the forwarding node should be higher than threshold energy. i.e., $E_{n,res} \geq E_{th}$.

Forwarding Metric

For node i, $N(i)$ is used to denote the set of its one hop neighbors. The source and sink nodes are labeled by S, $Dest$ respectively. $N_1(i)$ consists of the one-hop neighbors in one-hop area. $N_2(i)$ is two-hop neighbors of node i. The number of hops between a pair of nodes i and j is denoted by $N_h(i, j)$. Consequently, let S_p represent the expected packet progress towards sink for a given end-to-end delay D_{req}:

$$S_p = \frac{N_h(S, Dest)}{D_{req}}. \tag{8}$$

where, $N_h(S, Dest)$ represents the Number of hops from the Source to the Sink.

$FN^1_{(i\to j)}$ denotes one-hop Forwarding Node (FN) among the neighbors of node i and can forward packets towards the sink. Let $C_{(1, i)}$ denotes such available one-hop forwarder set for node i:

$$FN^1_{(i\to j)}(i) = \left\{ j\epsilon N_1(i) : N_h(i, Dest) - N_h(j, Dest) \right\} \quad (9)$$

Let $FN^2_{(i,j\to k)}$ denotes two-hop forwarding nodes for node i and can forward packets towards the sink. Let $C_{(2,i)}$ denotes such available two-hop forwarder set for node i:

$$\begin{aligned} & FN^2_{(i,j\to k)}(i) = \{ j\epsilon FN^2_{(i\to j)}(i) \\ & : N_h(i, Dest) - N_h(j, Dest) \}. \end{aligned} \quad (10)$$

The required packet progress speed offered by two-hop neighbors is determined. Thus $S_p(i, j, k)$ be the set of two-hop neighbors that provides required two-hop packet speed, which is calculated as:

$$S_p((i,j)\to k) = \frac{N_h(i, Dest) - N_h(k, Dest)}{ed_{(i,j)} + ed_{(j,k)}} \quad (11)$$

where, $ed_{(i, j)}$ is the expected channel/medium delay from node i to node j and $ed_{(j,k)}$ is expected media delay from node j to node k. Any (k) two-hop neighbor node of node i that has packet progress greater than $S_p((i,j) \to k)$ is selected as a forwarder and it is included in a set called potential Forwarder Node (FN_{set}) By taking residual energy level and the speed offered by forwarding nodes, THVR (Yanjun *et al.*, 2009) has the following definition:

$$\begin{aligned} ue_{(i,j,k)} &= \beta * \frac{S_p((i,j)\to k)}{\sum k\epsilon(FN_{set}) S_p((i,j)\to k)} \\ &+ (1-\beta) * \frac{Ej / Ej^0}{\Sigma(Ej, / Ej^0)}. \end{aligned} \quad (12)$$

The second term indicates residual energy of the nodes and initial energy at the instant of forwarding node (k) and β is a weighting factor. End-to-End delay performance is achieved for greater value β. Otherwise, it distributes traffic to nodes that has higher energy level. However, by fixing the coefficient of β value, real time and non-real time packets are serviced without any priority. In real-time application, each packet has different priority and different remaining time to meet the end-to-end delay. Hence, it is required to have adaptive coefficient depending on the remaining time to meet the end-to-end delay and prioritize the packets.

We propose an adaptive coefficient value:

$$\begin{aligned} sre_{(i,j,k)} &= f(rt) * \frac{S_p((i,j)\to k)}{\Sigma_{k\,\epsilon\, FN_{set}} S_p((i,j)\to k)} + f(rt) \\ &* \frac{MTX_i(j,k)}{\Sigma_{k\epsilon FN_{set}} MTX_i(j,k)} + (1 - f(rt)) * \frac{E_k / E_k^0}{\Sigma(E_k, / E_k^0)} \end{aligned} \quad (13)$$

where, $rt = D_{req}\text{-}t_j$ is the remaining time to satisfy the end-to-end delay of the packet and tj is the time required for a node j to forward the packet. The function $f(rt)$ should satisfy following two conditions:

i. The value of $f(rt) \in [0,1]$ and
ii. $f(rt)$ is an inverse function

Based on above conditions, the $f(rt)$ function can be:

$$f(rt) = \begin{cases} \dfrac{rt}{D_{req}} & for \dfrac{rt}{D^{req}} \le \dfrac{hi}{hs} \\ 1 - \dfrac{rt}{D_{req}} & for \dfrac{rt}{D_{req}} \ge \dfrac{hi}{hs}. \end{cases} \quad (14)$$

Whenever the node wants to send a data packet, it identifies the forwarding node based on (13). In this work, when a sensor node has less remaining time to meet the end-to-end delay requirement of a packet, it finds the forwarder in its two-hop neighborhood that has a higher speed of packet progress and it is more reliable. If sensor node has more remaining time to meet delay requirement, then sensor node selects forwarder node among its two-hop neighbors that have higher residual energy.

If there are no nodes in the two-hop neighbors that satisfy the required speed and reliable then the node position is checked to find out the node that is near to sink and has higher residual energy and, it is worthwhile to forward the packet. If there is no node in two-hop neighborhood of sender that does not satisfy the required conditions, then the packets are dropped. In another scenario, the success probability of packet (MTX values), the speed of packet progress and current status of energy available at the node is updated for every 2s. This update information is used to select the forwarding nodes among the two-hop neighbors of a node. This process is repeated for 7 times. If the total number of attempt to transmit the packet is exceeded 7, then the packet is dropped. The maximum number of re-transmissions of a packet in each node is based on the link loss rate.

Problem Formulation

We formulate real-time reliable data delivery using virtual coordinating routing for Wireless Sensor Networks (WSNs) as diversified objective with various constraints optimization problem.

Find $\{\pi_k(\text{Max}(sre_{(i,j,k)}))$
where $k \in FN^2_{(i,j\to k)}(i) \subseteq C_{(2,i)}\}$

Subject to

$ed\{FN^2_{(i,j\to k)}(i)\} \le D_{req}$

$MTX(i,j) \ge Pl(i,j)$

$E_{k,res} \ge E_{th}$ where $k \in FN_{(i,j\to k)}{}^2(i)$

The objective of the paper is to determine the optimal number of potential two-hop Forwarding Nodes (FNs) that is more reliable, offers required packet advancement towards the destination and has maximum residual energy.

Proposed Algorithm

In the proposed algorithm, there are three modules: A two-hop neighbor nodes module to find two-hop neighbor nodes, a Maximum Transmission Count (MTX) module to determine link reliability and a forwarding node metric x with the dynamic co-relation factor $f(rt)$ module to determine forwarding node. */Initially, the hop count for the sink is set to zero. The number of hops between a pair of nodes i and j is denoted by $N_h(i,j)$./* For a given node i its one-hopneighbor nodes and two-hop neighbor nodes are determined using Function 1. In function 1, each sensor node sends:

Function 1: Subset of two-hop nodes as a forwarding nodes

Data: i, $_{N1,i}$
Result: $C_{2,i}$
Initialization: $C_2,i = 0$
for ($i = 1; i \le |N_{1,i}|$ i++) **do**
  Add $i \in N_1(i)$ which covers max (uncovered ($N_2(i)$) to set $C_{2,i}$
  Add $i \in N_1(i)$ if uncovered ($N_2(i)$) covered by i only
  if ($C_{2,i} == C_{2,j}$) **then**
    Find Comb.(max($E_{n,res}$ and min(ed))
    add (Comb.(max($E_{n,res}$ and min(ed)) to set $C_{2,i}$
  end
end

HELLO packets to its neighbor nodes, in turn, the neighbor nodes send HELLO packets to its neighbors. Among these one-hop neighbors of node i, Function 1 determines the subset of one-hop nodes that cover a maximum number of two-hop nodes of node i. This subset of one-hop nodes is used to relay the packets to two-hop nodes. Whenever two or more one-hop neighbors cover the same number of two-hop neighbors, then selection of one-hop neighbor is based on residual energy and minimum end-to-end delay.

When node i has a packet to send, it searches for a set of potential forwarding nodes among the two-hop nodes. The packet progress towards the destination offered by each two-hop neighbor node of i is determined based on Equation 13 and the same equation is used in the proposed algorithm. If packet progress offered by the two-hop neighbors is greater than the required End-to-End delay, they are included to potential forwarder set FN_{set} where $FN_{set} \subseteq C_{2,j}$. To choose one among forwarder set FN_{set}. In the next step, success probability between node i, j is determined by using function 3, residual energy at forwarding node is calculated using the Equation 7.The transmission delay of the packet from node i to node j is determined based on Equation 5. For each Forwarding Node in FN_{set} a dynamic co-relation factor $f(rt)$ is used to relate packet progress, success probability and remaining energy. If the co-relation factor $f(rt)$ value is small then it favors to find the forwarder that has a higher speed of packet progress and higher reliability but forwarding node has less remaining time for forwarding packets. If downstream node has more remaining time to forward packet then co-relation factor $f(rt)$ value favor node to select the forwarder node among its two-hop neighbors (FN_{set}) that has higher residual energy. If there are no nodes in two-hop neighbors that satisfy the required speed and reliability then the node position is checked to find out the node is near to sink and has higher residual energy and it is worthwhile to forward the packet. If there is no node in the two-hop neighborhood of sender that not satisfies the required conditions, then the packets are dropped.

Algorithm 2: RRDCVR Algorithm

Data: $N(i)$, $N_2(i)$, $N_h(i, Dest)$, $N_h(k, Dest)$, $Dest$, i
Result: $FN^2_{(i,j\to k)}(i), FN^1_{(i\to j)}(i)$
Initialization: $FN^2_{(i,j\to k)}(i), = 0, E_{avl} = 5J, h_{Dest} = 0$

$$D_{req} = \frac{N_h(i, Dest)}{ed(i, Dest)}$$

for each $k \in FN^2_{(i,j\to k)}(i)$ do

$$S_p((i,j) \to k) = \frac{N_h(i, Dest) - N_h(k, Dest)}{ed(i,j) + ed(j,k)}$$

 If ($S_p((i,j) \to k) \ge D_{req}$) then
  $FN_{set} = S_p((i,j) \to k)$
  for each $k \in FN_{set}$ **do**
   if ($MTX(MTX(i,j) \ge 0.5),k) \ge 0.5$) **then**

$$sre_{(i,j,k)} = f(rt) * \frac{S_p((i,j) \to k)}{\sum_{k \in FN set} S_p((i,j) \to k)} + f(rt) * \frac{MTX(j,k)}{\sum_{k \in FN_{set}} MTX(j,k)} + (1 - f(rt)) * \frac{E_k^{res}}{\sum_{k \in FN_{set}} E_k^{res}}$$

   end
   return (π(Max(sre $_{(i,j,k)}$)))
  end
 end
end
return

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Function 3: MTX(i,j)
Data: $MaxRetry$, $Psuc(x, y)$, d_r, d_t, $minPsuc$
Result: $MTX(i,j, y)$
Initialization: MaxRetry = 7
$Psuc(x, y) = d_r * d_t$
if ($curP_{suc}(i,j) \geq Pl(i,j)$) **then**

$$MTX(i, j) = \frac{1}{curP_{suc}(i, j)}$$

else

$$MTX(i, j) = \frac{1}{Pl(i, j)}$$

end

Simulation Parameters

The proposed protocol RRDVCR is simulated and evaluated using (NS-2, [Online]). It is compared with THVR (Yanjun *et al*., 2009) and SPEED (He *et al*., 2005). The simulation configuration consists of 200 nodes located in a 200 m^2 area. Nodes are distributed following Poisson point process with a node density of 0.005 node/m^2. The source nodes are located in the region (15, 25m) while the sink in the area (155, 125 m). The source generates a CBR flow of 1 packet/second with a packet size of 150 bytes. The MAC layer, link quality and energy consumption parameters are set as per Mica2 Motes (Crossbow Motes) with MPR400 radio as per THVR (Yanjun *et al*., 2009). The simulation parameters are summarized in Table 2. The proposed algorithm is compared with two-hop speed THVR (Yanjun *et al*., 2009), one-hop speed (He *et al*., 2005) and energy balancing protocols. These are QoS-aware protocols and select next forwarding nodes based on one-hop information and two hop information respectively, However, these protocols are proactive and causing control overhead, additional delay and computational complexity. We want to compare proposed protocol with THVR and SPEED to illustrate the performance improvement, the comparison of Packet Deadline Miss Ratio (PDMR), Energy Consumed Per Packet (ECPP i.e., the total energy expended divided by the number of packets effectively transmitted), the packet average delay (mean of packet delay) and worst case delay (largest value sustained by the successful transmitted packet) are obtained.

Simulation Results

In this section, the performance of the proposed algorithm RRDVCR based on simulation results are discussed.

Figure 2 shows the number of packets missed with given different end-to-end delay. In the beginning, miss ratio is between 78 and 80% in the proposed protocol while in THVR (Yanjun *et al*., 2009) protocol it is 80%. The packet loss increases as the forwarding nodes are not offering the required packet progress towards the destinations. As end-to-end delay is increased, the forwarding nodes meet the required end-to-end delay. With the 1200s as end-to-end delay, it is observed that a number of packets missed are THVR lower compared to the existing protocol as more number of forwarding nodes are available to forward the packets. At interval 1500s to 1800s end-to-end delay, almost all the packets reach the destination. The number of packets missed is almost zero as void space between the forwarding nodes is less and more forwarding nodes are available with the required speed.

Table 2: Simulation parameters

Simulation parameters	Value
Number of nodes	200
Simulation area	200×200 m
Transmission range of node	25 m
Initial energy	5 J
End-to-end delay requirement	800-1500 ms
Max number of transmission	7
Source location	15×25
Destination location	155×125
Energy required for transmission	0.0635 J
Energy required for receiving	0.0525 J
Energy during sleep	0.000012 J
Energy required during idle	0.024 J
Application	CBR
Source packet generation rate	1 packet/sec
Packet size	150 bytes
MAC layer	Mac/802.11
Interface queue type	CMUPriQueue
MTX calculation	10 s

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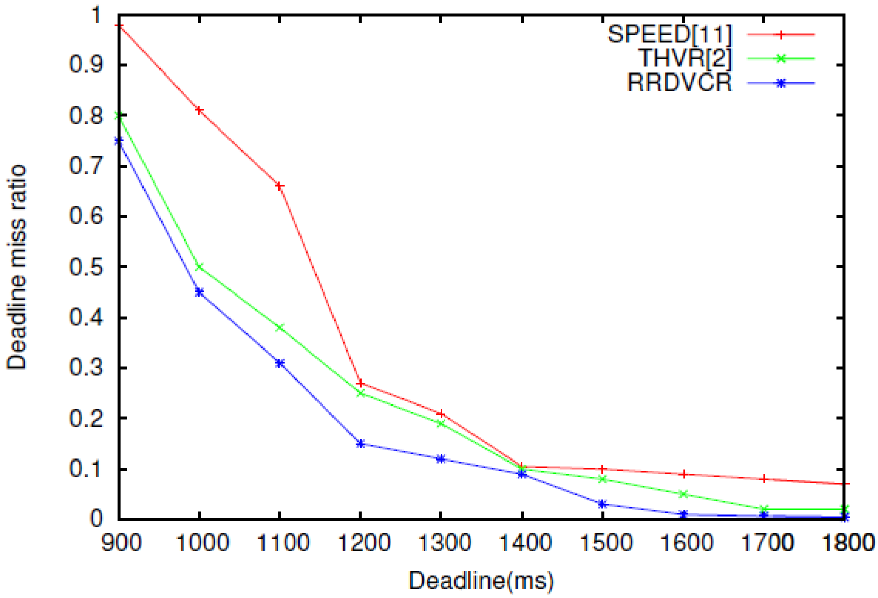

Fig. 2: Delivery miss ratio with varied end-to-end delay. (i) SPEED; (ii) THVR; (iii) RRDVCR

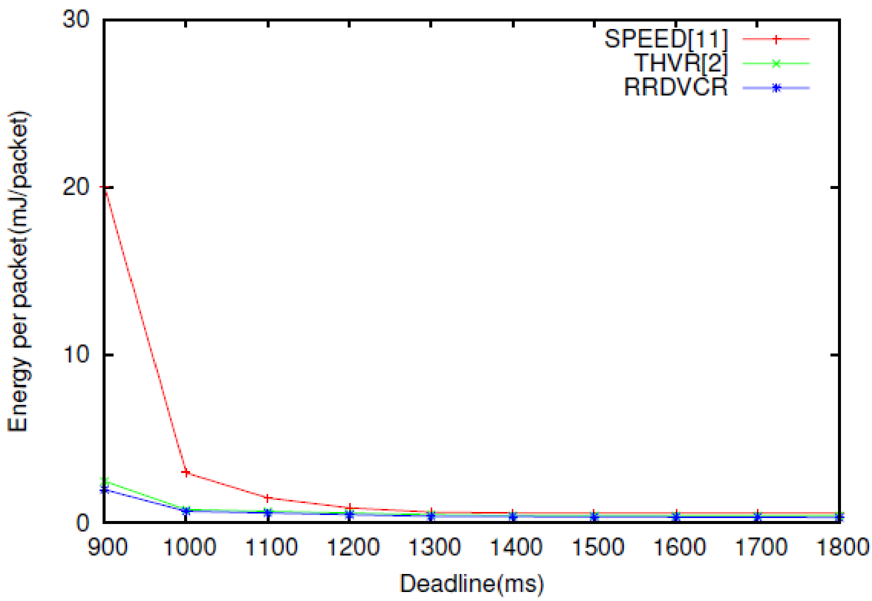

Fig. 3: Energy consumed per successfully transmitted packet. (i) SPEED; (ii) THVR; and (iii) RRDVCR

Figure 3 shows consumption of energy by each packet that are transmitted successfully from the source node to the sink node. In THVR (Yanjun *et al*., 2009), a huge number of control packets are exchanged since it uses proactive approach for updating two-hop neighbor information. The RRDVCR forward packets in a smaller number of hops with reduced number of control packets and hence it requires less energy. It is observed from the figure that the energy consumption is more during 900 to 1100s deadline.

Figure 4, shows the performance of RRDVCR with multiple source nodes. The probability of delivering packets successfully decreases as transmission from multiple source nodes generate huge traffic in networks that cause congestion, increase channel contention in the network resulting in higher packet collision and re-transmission of packets. It is observed that as the number of source nodes increase, the number of packets unable to reach the destination also increases. The packet deadline miss ratio is about 23% in RRDVCR when a number of sources in the network are 4.

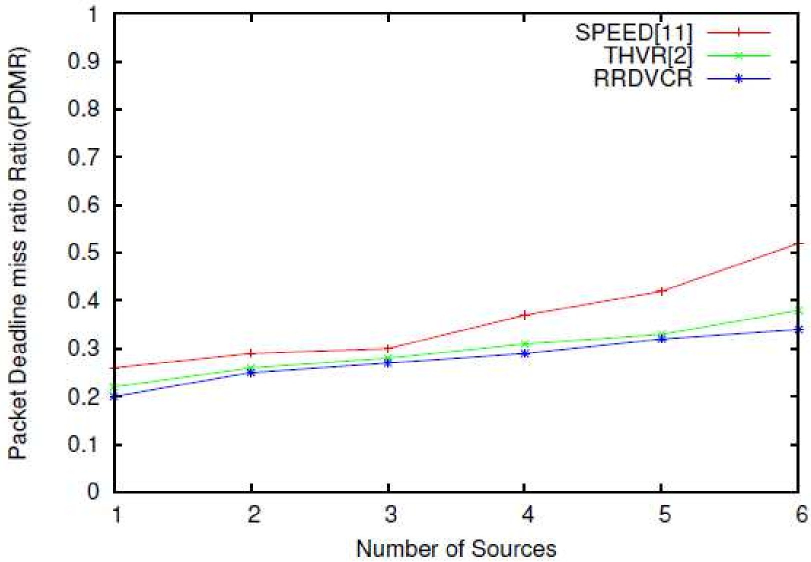

Fig. 4: Delivery Miss Ration with a varied number of sources. for (i) SPEED; (ii) THVR; and (iii) RRDVCR; while the number of source nodes increases from 1 to 6

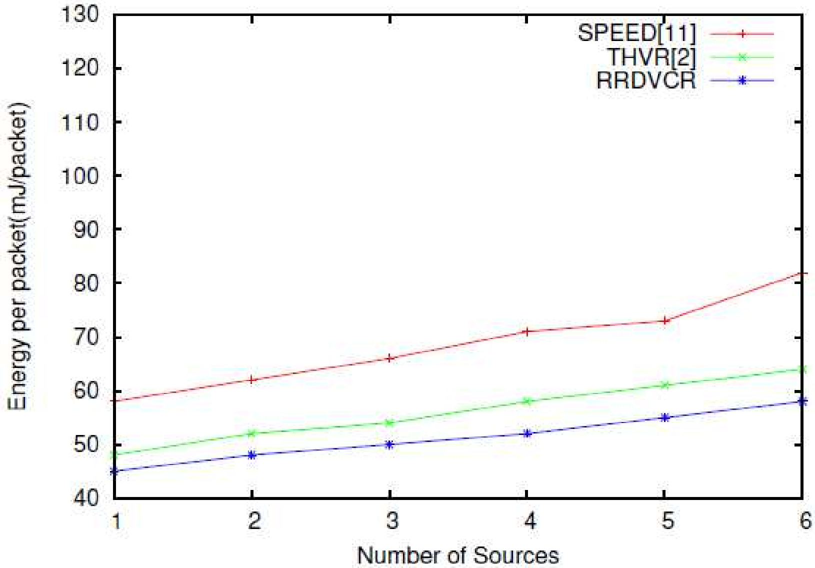

Fig. 5: Energy consumed per successfully transmitted packet with a varied number of source nodes. (i) SPEED; (ii) THVR; and (iii) RRDVCR

The number of source nodes is increased from 4 to 6, the packet deadline miss ratio increased from 23 to 24% in RRDVCR, whereas in THVR (Yanjun *et al*., 2009) it increases from 24 to 25%. In SPEED (He *et al*., 2005) protocol, the packet deadline miss ratio is about 50% since it considers one-hop information to select forwarding nodes and hence packets travel more distance to reach the destination.

Figure 5 shows the required energy for each packet trans-mission with varying number of source nodes on the networks. One common characteristic observed is that for all existing protocols and the proposed protocol, energy consumption during transmission of packets increases with the increase in the number source nodes in the network. The RRDVCR protocol is energy-efficient compared to existing protocols as it delivers packets in a smaller number of hops with a minimum number of control packets. RRDVCR uses the piggyback concept to update link status between nodes. In THVR (Yanjun *et al*., 2009), energy consumption is more because of (i) Two-hop information is updated frequently with control packets which require more energy. (ii) The increase in a number of source nodes results in more number of transmission of packets from different sources, which leads to congestion at different layers. The energy consumption is 46 mJ in RRDVCR, 48 mJ in THVR (Yanjun *et al*., 2009) and 58 mJ in SPEED (He *et al*., 2005). As the number of sources increases to 6, energy consumption increases. It is 80 mJ in SPEED (He *et al*., 2005), 66 mJ in THVR (Yanjun *et al*., 2009) and 49 mJ in our protocol RRDVCR. It indicates that RRDVCR results in a lower value of deadline miss ratio and lower consumption of energy for each successfully transmitted packet. It is 74% more efficient than THVR (Yanjun *et al*., 2009) and SPEED (He *et al*., 2005).

Figure 6 shows impact of co-relation factor $f(rt)$ on network performance. When the co-relation factor $f(rt)$ is set to 0.1, the co-relation factor favours energy balance and ignores the end-to-end delay. There are a huge number of packets unable to reach the destination within the specified end-to-end delay. When the co-relation factor is set to 0.1, with a rigid end-to-end delay (900 ms), 80% of packets are unable to reach the destination. As end-to-end delay is relaxed, the forwarding nodes get time to forward more number of packets and the packet miss ratio gradually reduces. Whenever corelation factor $f(rt)$ is set to 0.9, it meets the end-to-end delay requirement rather than energy balance. Each packet has different remaining time to meet the deadline and each node services a packet differently and hence the co-relation factor $f(rt)$ is varied dynamically. The packet miss ratio decreases to 7 to 8%.

Figure 7 shows a number of packets miss rate before the forwarding nodes fail to forward packets. The maximum tolerance for probability of forwarding node failure is set to 0.5 in our simulation. Whenever the probability of forwarding node failure exceeds 0.5, then such forwarding node is called as a dead node. The probability of forwarding node failure means either it does not satisfy the packet progression speed or the residual energy is less than the threshold energy. The effects of forwarding nodes failure and re-transmission are not evaluated in SPEED (He *et al*., 2005) and THVR (Yanjun *et al*., 2009).

Figure 8 illustrates the number of hops that exist between the source and the destination an optimum number of hops between source and destination is achieved in RRDVCR. When the network has 10 nodes, the hops between source to destination is about 4 which is 60% of the total network size. This is because the network is sparse and nodes are placed at a far distance, to transfer data packets between the source and the destination; 60% of intermediate nodes act as a router to forward packets. In THVR (Yanjun *et al*., 2009) the number of hops between source and destination is more when compared to proposed algorithm; this is because it does not estimate the success probability between nodes and the forwarding node selection is based only on geographic distance progress offered by two-hop neighbors. The number of hops between the source and the destination for network size 20,30,40 is 9,12,17 in proposed algorithm, in THVR (Yanjun *et al*., 2009) it is 13,19,26 and it is 23,26,34 in SPEED (He *et al*., 2005). This difference is due to the intermediate nodes having its neighbor node's probability of success and neighbor node packet progress towards the destination in terms of a number of hops. As the simulation progresses all the nodes get an update of success probability of its neighbor node and a number of hops remaining to reach the destination, the nodes in proposed algorithm converge fast as compared to THVR (Yanjun *et al*., 2009) and SPEED (He *et al*., 2005). Because of these reasons, the number of hops between the source and the destination is less in the proposed algorithm.

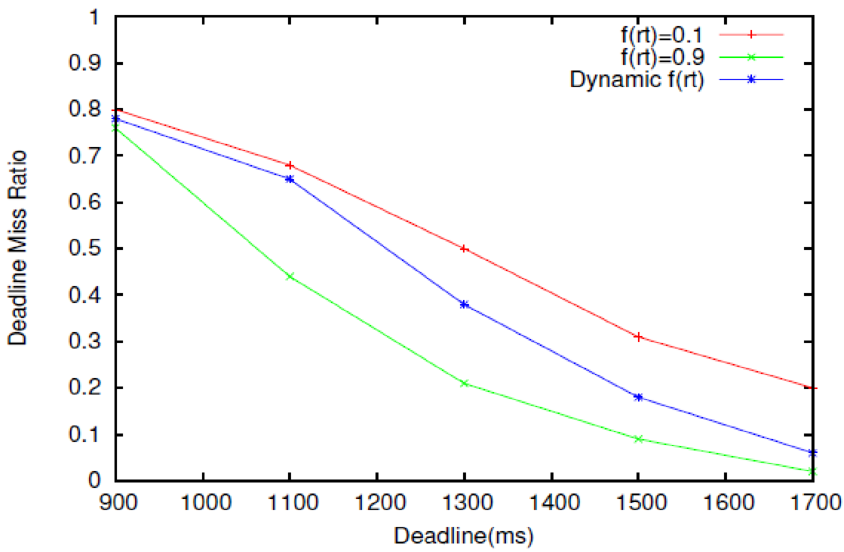

Fig. 6: The Impact of the different value of co-relation factor

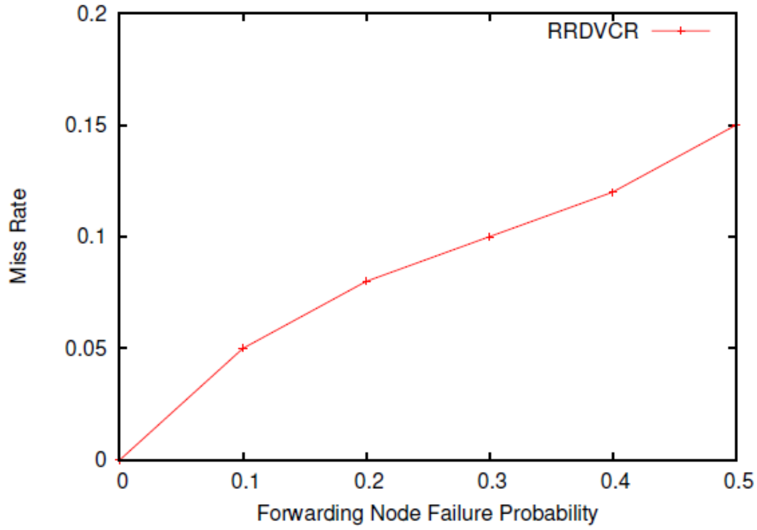

Fig. 7: The probability of node failure with delivery miss ratio

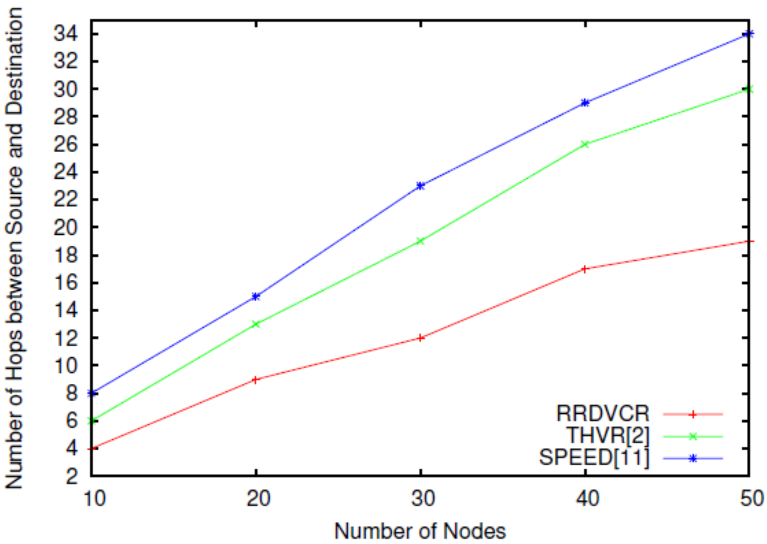

Fig. 8: Comparison of number of hopes. (i) SPEED; (ii) RRDVCR; and (ii) THVR (Yanjun *et al*., 2009)

Figure 9 shows the number of re-transmissions for varying number of nodes in the network. In THVR (Yanjun *et al*., 2009), routing decision is only based on the geographical location of a node and transmission speed from each sensor node to its two-hop neighbor; the success probability offered by two-hop neighbors is not considered. Hence, it results in more message exchanges, packet collision, network congestion and re-transmission in THVR (Yanjun *et al*., 2009). It does not optimize hop count between source and destination. During the initial network setup, the number of re-transmission is about 6. This is because nodes are placed at a far distance and exchange control packets to determine the neighbors and its success probability, results in the busy channel and packet collision. As the number of nodes in the network increase, the number of re-transmissions decreases because of the vicinity of neighbor is clear, void area decreases and the node has alternative option to forward the packets. When the network size is between 40 and 50, the number of re-transmissions reduces from 4 to 3 in proposed RRDVCR, whereas in THVR (Yanjun *et al*., 2009) and SPEED (He *et al*., 2005) it remains same. Similarly, the number of re-transmissions is decreased when node density increases from 90 to 100. A sensor node forwards the packet to its one of the two-hop neighbor which provides better transmission speed having higher residual energy and success probability.

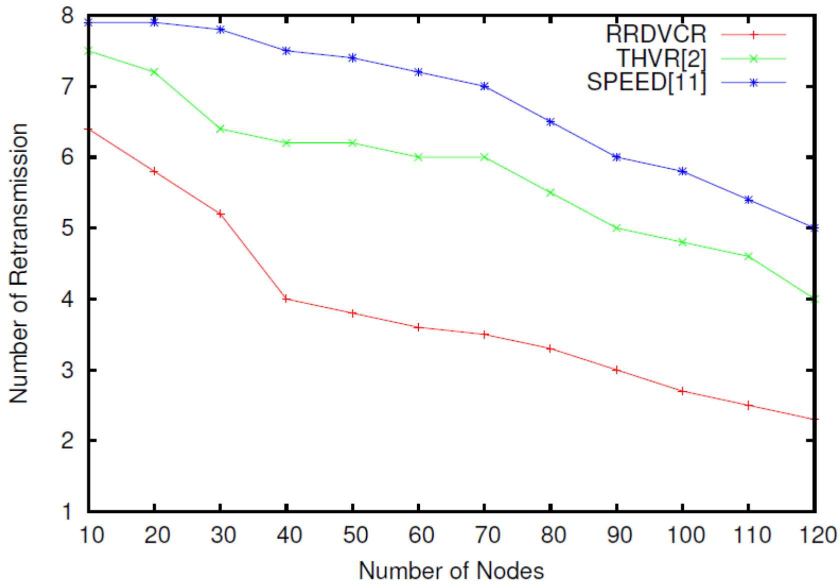

Fig. 9: Number of re-transmission

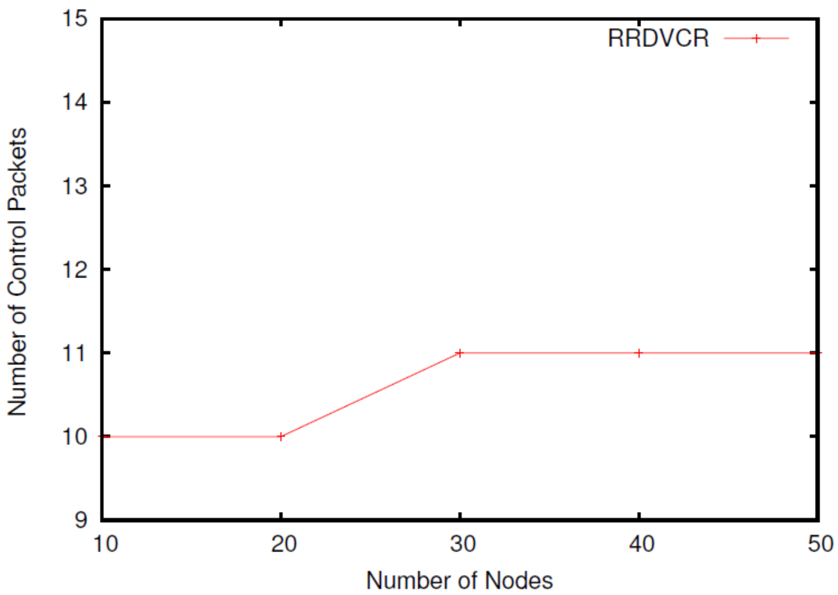

Fig. 10: Exchanged control packet

Figure 10 illustrates the number of control packet exchanged to update the status of a two-hop neighbor in the network. In the proposed algorithm RRDVCR, forwarding nodes send selective ACK to a sensor node; a node that receives selective ACK updates its one-hop success probability in ACK and then forwards it to the descendant nodes. Each ACK packet gives the current status of all intermediates node from the source and the destination. In THVR (Yanjun *et al*., 2009), the two-hop delay information is not updated often. To update this two-hop delay information number of control packets are exchanged which results in higher energy consumption.

The Figure 11 illustrates the number of control packet exchanged to update the status of a two-hop neighbor in the network. In proposed algorithm RRDVCR forwarding node send selective ACK to the sensor node, a node that receives selective ACK, update its one-hop success probability in ACK then forward it to descendant nodes. Thereby each ACK packet gives current status of all intermediate node from source and destination. In THVR (Yanjun *et al*., 2009) two-hop delay information is not updated often. To update this two-hop delay information, more number of control packets are exchanged which results in energy consumption.

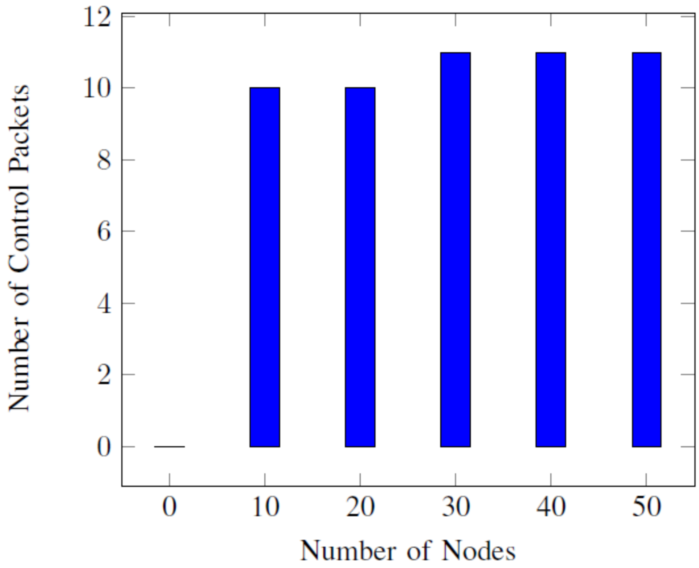

Fig. 11: Exchanged control packet

Conclusion

The Proposed RRDVCR is based on virtual coordinate routing. The proposed protocol employs a link quality estimation method (MTX: Maximum Transmission Count) which helps in selecting the link that has high reliability. The link reliability, packet advancement and residual energy of node are the parameters considered while selecting potential forwarding nodes. The dynamic co-relation factor is introduced in this paper that co-relates different metric during potential forwarding node selection and the real-time or non-real time packets are serviced accordingly remaining time meet the deadline. The simulation results show improvement in packet success delivery ratio within specified deadline, energy consumption during transmission of the packet for varied number of the source node is decreased. With dynamic co-relation factor, the number of packets missed to reach the destination within end-to-end delay is reduced.

As future work, we plan to provide a differentiation routing path for diversified traffic and mobile nodes.

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Author's Contributions

Venkatesh: Establishment of the state of art, Contribute to the design of mathematical model, drafting and writing the article (about 50- 60%), the simulation results analysis and interpretation of simulation paramters. Participated in all experiments and writing code.

C.S. Sengar: Contribute to the development of the MTX as a link reliability model. Participated in all experiments. Contribute in writing the article (about 15-20%).

K.R. Venugopal: Contribute to the development of the problem statement and validation of simulation results. Contribute in writing the article (about 10-20%), the simulation results analysis and interpretation of simulation results.

S.S. Iyengar: Contribute in drafting and reviewing the paper, analysis and interpretation of results.

L.M. Patnaik: Designed research plan. Contribute in grammatical corrections and reviewing the paper, analysis and interpretation of simuation results.

Ethics

This article is the novel contribution of the authors There is no ethical issue involved in this article.

References

Ahmed, A., K.A. Bakar, M.I. Channa, K. Haseeb and A.W. Khan, 2015. TERP: A trust and energy aware routing protocol for wireless sensor network. IEEE Sensors J., 15: 6962-6972. DOI: 10.1109/JSEN.2015.2468576

Akkaya, K. and M. Younis, 2003. An energy-aware QoS routing protocol for wireless sensor networks. Proceedings of the 23rd International Conference on Distributed Computing Systems Workshops, May 19-22, IEEE Xplore Press, Providence, pp: 710-715. DOI: 10.1109/ICDCSW.2003.1203636

Akkaya, K. and M. Younis, 2005. A survey on routing protocols for wireless sensor networks. J. Ad Hoc Netw., 3: 325-349. DOI: 10.1016/j.adhoc.2003.09.010

Amjad, M., M.K. Afzal, T. Umer and B.S. Kim, 2017. QoS-aware and heterogeneously clustered routing protocol for wireless sensor networks. IEEE Access, 5: 10250- 10262. DOI: 10.1109/ACCESS.2017.2712662

Boughanmi, N. and Y.Q. Song, 2008. A new routing metric for satisfying both energy and delay constraints in wireless sensor networks. J. Signal Proc. Syst., 51: 137-143. DOI: 10.1007/s11265-007-0102-5

Chen, C.S., Y. Li and Y.Q. Song, 2008. An exploration of geographic routing with k-hop based searching in wireless sensor networks. Proceedings of the 3rd International Conference on Communications and Networking in China, Aug. 25-27, IEEE Xplore Press, Hangzhou, pp: 376381. DOI: 10.1109/CHINACOM.2008.4685045

Cheng, L., J. Niu, C. Luo and T. He, 2016. Achieving efficient reliable flooding in low-duty-cycle wireless sensor networks. IEEE/ACM Trans. Network., 24: 3676-3689. DOI: 10.1109/TNET.2016.2549017

Cheng, L., J. Niu, J. Cao, S.K. Das and Y. Gu, 2014. QoS aware geographic opportunistic routing in wireless sensor networks. IEEE Trans. Parallel Distributed Syst., 25: 1864-1875. DOI: 10.1109/TPDS.2013.240

Chipara, O., Z. He, G. Xing, Q. Chen and X. Wang *et al*., 2006. Real-time power-aware routing in sensor networks. Proceedings 14th IEEE International Workshop Quality Service, Jun. 19-21, IEEE Xplore Press, New Haven, pp: 83-92. DOI: 10.1109/IWQOS.2006.250454

Crossbow Motes, [Online]. http://www.xbow.com

Entezami, F., M. Tunnicliffe and C. Politis, 2014. Find the weakest link. IEEE Vehicular Technol. Magazine, 9: 28-38. DOI: 10.1109/MVT.2014.2333693.

Felemban, E., C.G. Lee and E. Ekici, 2006. MMSPEED: Multipath multi-speed protocol for QoS guarantee of reliability and timeliness in wireless sensor networks. IEEE Trans. Mobile Comput., 5: 738-754. DOI: 10.1109/TMC.2006.79

Feng, R., T. Li, Y. Wu and N. Yu, 2016. Reliable routing in wireless sensor networks based on coalitional game theory. Institution Eng. Technol. Commun., 10: 1027-1034. DOI: 10.1049/iet-com.2015.0884

Han, K., J. Luo, L. Xiang, M. Xiao and L. Huang, 2015. Achieving energy efficiency and reliability for data dissemination in duty-cycled WSNs. IEEE/ACM Trans. Network., 23: 1041-1052. DOI: 10.1109/TNET.2014.2312973

He, T., J. Stankovic, T. Abdelzahar and C. Lu, 2005. A spatiotemporal communication protocol for wireless sensor networks. IEEE Trans. Parallel Distributed Syst., 16: 995-1006. DOI: 10.1109/TPDS.2005.116

Jalel, B.O. and B. Yahya, 2010. Energy efficient and QoS routing protocol for wireless sensor networks. J. Parallel Distributed Comput., 70: 849-857. DOI: 10.1016/j.jpdc.2010.02.010

Joseph, P., J. Hill and D. Culler, 2004. Versatile low Power media access for wireless sensor networks." Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems, ACM, pp: 95-107.

Jung, J., S. Park, E. Lee, S. Oh and S.H. Kim, 2010. OMLRP: Multi-hop information based real-time routing protocol in wireless sensor networks. Proceedings of the IEEE Wireless Communications and Networking Conference, Apr. 18-21, IEEE Xplore Press, Sydney, pp: 1-6. DOI: 10.1109/WCNC.2010.5506491

Katia, O., V. R.ajendran and J.J. Garcia-Luna-Aceves, 2006. Energy-efficient, collision-free medium access control for wireless sensor networks. Wirel. Netw., 12: 63-78.

Li, Y., C.S. Chen, Y.Q. Song and Z. Wang, 2007. Real-time QoS support in wireless sensor networks: A survey. IFAC Proc., 40: 373-380. DOI: 10.3182/20071107-3-FR-3907.00052

Li, Y., C.S. Chen, Y.Q. Song, Z. Wang and Y. Sun 2008. A two-hop based real-time routing protocol for wireless sensor networks. Proceedings of the IEEE International Workshop on Factory Communication Systems, May 21-23, IEEE Xplore Press, Dresden, pp: 65-74. DOI: 10.1109/WFCS.2008.4638730

Lou, W. and J. Wu, 2002. On reducing broadcast redundancy in adhoc wireless networks. IEEE Trans. Mobile Comput., 1: 111-122.

Nefzi, B. and Y.Q. Song, 2007. Performance analysis and improvement of zigbee routing protocol. IFAC Proc. FET, 40: 199-206. DOI: 10.3182/20071107-3-FR-3907.00027

Niu, J., L. Cheng, Y. Gu, L. Shu and S.K. Das, 2013. 2R3E: Reliable reactive routing enhancement for wireless sensor networks. IEEE Trans. Indus. Informat., 10: 784-794. DOI: 10.1109/TII.2013.2261082

NS-2, [Online]. http://www.isi.edu/nsnam/ns/

Pinto, P., A. Pinto and M. Ricardo, 2015. Cross-layer admission control to enhance the support of real-time applications in WSN. IEEE Sensors J., 15: 6945-6953. DOI: 10.1109/JSEN.2015.2467329

Prabh, K.S. and T.F. Abdelzaher, 2007. On scheduling and real-time capacity of hexagonal wireless sensor networks. Proceedings of the 19th Euromicro Conference on Real-Time Systems, Jul. 4-6, IEEE Xplore Press, Pisa, Italy, pp: 136-145. DOI: 10.1109/ECRTS.2007.23

Pradittasnee, L., S. Camtepe and Y.C. Tian, 2017. Efficient route update and maintenance for reliable routingin large-scale sensor networks. IEEE Trans. Indus. Informat., 13: 144-156. DOI: 10.1109/TII.2016.2569523

Quang, P.T.A. and D.S. Kim, 2012. Enhancing real-time delivery of gradient routing for industrial wireless sensor networks. IEEE Trans. Indust. Informat., 8: 61-68. DOI: 10.1109/TII.2011.2174249

Sarma, H.K.D., R. Mall and A. Kar, 2010. E^2R^2: Energy-efficient and reliable routing for mobile wireless sensor networks. IEEE Syst. J., 10: 604 616. DOI: 10.1109/JSYST.2015.2410592

Spohn, M.A. and J.J. Garcia-Luna-Aceves, 2004. Enhancing broadcast operations in adhoc networks with two-hop connected dominating sets. Proceedings. IEEE MASS, pp: 543-545.

Umar, I.A., Z.M. Hanapi, A. Sali and Z.A. Zulkarnain, 2017. TruFiX: A configurable trust-based cross layer protocol for- wireless sensor networks. IEEE Access, 5: 2550-2562. DOI: 10.1109/ACCESS.2017.2672827

Xu, Z., L. Chen, C. Chen and X. Guan, 2016. Joint clustering and routing design for reliable and efficient data collection in large-scale wireless sensor networks. IEEE Internet Things J., 3: 520-532.

Yanjun, L., C.S. Chen, Y.Q. Song, Z. Wang and Y. Sun, 2009. Enhancing real-time delivery in wireless sensor networks with two-hop information. IEEE Trans. Indus. Informat., 5: 113-122. DOI: 10.1109/TII.2009.2017938