Design of Composite Routing Metrics in LOADng Routing Protocol for IoT Applications

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***Abstract*—Machine to machine communication has gained increasing importance in the context of Internet of Things (IoT). The existing routing protocols for low-power, lossy networks (LLNs) mainly support multipoint to point or point to multipoint communications and have very limited support for point to point communication. The LOADng routing protocol is a source initiated reactive protocol with support for point to point communication. In this paper, a composite routing metric is proposed to improve the packet delivery ratio and the lifetime of a network using LOADng routing protocol. The results obtained through simulation show that using a composite metric can significantly improve the performance of LOADNg routing protocol for low-power, energy constrained networks with sparse traffic.**

Keywords–IoT; LOADng routing protocol; routing metrics, low-power lossy networks.

I. Introduction

The Internet of Thing (IoT) has gained importance in recent years. The IoT is composed of smartphones, laptops, healthcare and home devices, and industry sensors [1]. Machine to machine communication has gained increasing importance in the context of Internet of Things (IoT) [2]. MTC avoids human intervention, and the machines communicate with each other to form an intelligent environment. MTC is an enhancement of the third generation partnership project (3GPP) [3]. Low power devices or sensor nodes constitute the majority of elements in IoT. The sensor nodes are limited in memory, bandwidth and energy requirements and often run on non-rechargeable batteries. These hardware constrained devices form a network known as low power lossy networks (LLNs) and follow IEEE802.15.4 standard [4].

The primary driving force behind the growth of IoT is the effectiveness of Ipv6 over low power lossy personal area networks (6LoWPAN). 6LoWPAN is an adaptation layer between the network layer and the data link layer [5]. The primary function of the 6LoWPAN is to convert IPv6 packets from the network layer into short IEEE802.15.4 frames. To encapsulate IPv6 packets in IEEE802.15.4 frames [4], 6LoWPAN requires performing IPv6 header compression, fragmentation, and defragmentation. The 6LoWPAN adaptation layer also performs routing between the nodes within the network. There exist many protocols for LLNs and consider the network to follow a source - sink architecture. Thus, most of the protocols are designed to support multipoint-to-point (M2P) or point-to-multipoint (P2M) communications. Moreover, they have limited options for point-to-point (P2P) communication.

IoT is more than just connecting a collection of sensor nodes to a common server and making it available from anyplace in the world through the Internet. IoT has enabled machines to communicate with each other without human intervention. So, the demand for one-to-one communication is as much as or even more than that of M2P or P2M. Devices in IoT are mostly low power and hardware constrained. Routing is an important procedure in IoT as the choice of the routing protocol can significantly improve the network performance. The selection of routing protocol is to support the application requirements [6]. Based on the procedure of establishing routes, routing protocols fall into three categories, namely, proactive, reactive and hybrid routing schemes. The proactive routing scheme periodically sends a short probe, such as a HELLO message, to its neighboring node. The node establishes a route to all possible destinations. When there is a data packet ready for transmission to a destination, the node checks its routing table and sends the data packet on the pre-calculated route. The reactive routing scheme, on the other hand, initiates a route discovery only when there is some data packet to be sent across the network over to a destination node and the routing information to the destination is not available at the sending node. The route to the destination is immediately available in proactive routing, but reactive routing needs time to discover a route to the destination. The hybrid routing scheme is a combination of both proactive and reactive routing schemes. The reactive routing scheme is best suited for a network with P2P communication. The Lightweight On-demand Ad hoc Distance-vector Routing Protocol - Next Generation (LOADng) [7] is a routing protocol specifically designed to address P2P communication between energy and hardware constrained nodes.

LOADng is a simplified adaptation of Ad-hoc On-demand Distance Vector (AODV) and is a reactive routing protocol for LLNs. LOADng is a source initiated reactive routing protocol and generates a route discovery when there is some data to be sent to the destination. The route is maintained as long it is in use and nodes discard any idle route from its routing table. Traditionally, LOADng uses hop count as the metric during route discovery. The hop count does not consider the constraints of the nodes in the network leading to the premature death of nodes, reducing the network lifetime.

The impact of different routing metrics on the performance of routing protocols in wireless sensor networks (WSNs) are widely studied in the literature [8]–[11]. Yang et al. [12] discuss the design considerations of routing metrics for multihop wireless networks and Zahariadis et al. [13] discuss the design aspects of primary and composite routing metrics from the LLNs perspective. The Routing Protocol for Low power

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and Lossy Networks (RPL) is a proactive rank based routing protocol specifically designed for LLNs and is standardized by the Routing Over Low power and Lossy networks (ROLL) working group [14]. RPL calculates the rank of a node using the route metrics. This rank is used to establish the node's position in a destination oriented directed acyclic graph (DODAG). An appropriate choice of RPL routing metrics can significantly improve Quality of Service (QoS) requirements in an LLN [15]–[21]. However, they all consider the LLNs as M2P and P2M networks and have the least support for P2P communication. Routing by Energy and Link quality (REL) is a variant of AODV and uses energy and link quality as the route metrics [22], [23]. The node requires sending periodic HELLO messages to maintain the list of neighbors.

The routing metrics fall into two categories, namely, node based and link based. Node based routing metrics consider the properties of the node such as the remaining energy, number of active connections through the node and transmission queue utilization. Link based routing metrics quantify the link properties between the nodes such as the Received Signal Strength Indicator (RSSI) and the expected transmission count (ETX). Each metric enumerates one or more distinct characteristics needed to enhance the QoS required such as packet delivery ratio, packet loss, latency, reliability, energy consumption and network lifetime. The selection of route metrics depends on the requirement of the application.

In literatures, network lifetime is defined as the time taken in the network for the first node to die or a percentage of nodes to die. Network lifetime can also be defined as the time taken by the network to get partitioned. This definition considers the time period when communication is not possible with one or more nodes in the network. The network can be represented as a fully connected graph where the nodes of the graph are the devices in the network and the connectivity between the devices form the edges of the graph. Efficient utilization of node energy is the prime concern to improve the network lifetime.

A Routing protocol that uses Remaining Energy (RE) metric can find a path with nodes which has maximum remaining energy. However, overusing such paths can quickly deplete the nodes energy. Live routes (LR) metric keeps track of the number of live or active routes through a node. The higher the value of LR, the higher the traffic through the node. Energy consumption rate of a node significantly depends on the energy required for transmitting and receiving data packets. The number of active routes through a node indicates the traffic load which is directly proportional to the energy consumption rate of the node.

LOADng has a provision to incorporate user-defined metrics in its METRIC TLV, and can contain 32-bit dimensionless additive metrics with single precision float value. It is possible to exploit this feature of LOADng to perform route discovery using alternate route metrics. However, there are hardly any works on route metrics design that address the node congestion due to large number of active routes.

In this paper, we propose a composite routing metric for LOADng to improve the lifetime of a network with P2P traffic. The network under consideration has sparse traffic density and the nodes have strict energy constraints. We propose a composite route metrics called LR+RE which combines LR, RE and Hop Count (HC) metrics. The resolution is to deal with the node congestion and the residual energy of the node to improve the network lifetime, improve the reliability of packet transmission and reduce the energy wastage of the nodes. We compare our results with the traditional HC metrics and also with LR and RE as the primary metrics. The rest of the paper is organized as follows. Section II gives a brief overview of the LOADng routing protocol. Section III explains the routing algebra used. Section IV defines and describes the composite routing metrics for LOADng. Section V discusses the numerical results. The conclusion and future works are presented in Section VI.

II. LOADng Routing Protocol

LOADng routing protocol is a simplified version of AODV routing protocol. LOADng has eliminated the HELLO messages of AODV and mandates that only the intended destination replies to the request message. LOADng uses a single message sequence number to uniquely identify its protocol messages. To ensure the freshness of the route, LOADng forces each node to monotonically increase its message sequence number with each protocol message which also ensures a loop-free path [24]. Clausen et al. [7] discuss how each node should process a LOADng protocol message and specifies the condition on which LOADng protocol messages are forwarded.

The route discovery in LOADng starts with the source initiating a Route Request (RREQ) message to a destination when the source has packets to send to the destination and a route entry for the destination is not available in its routing table. The source node will broadcast the RREQ message across the network. The intermediate nodes will process and rebroadcast RREQ messages. The destination node generates Route Reply (RREP) messages which will unicast back to the source node. A Route Reply Acknowledgement (RREP_ACK) message is generated by the intermediate nodes if the route reply acknowledgment required flag in the RREP message is true. This process will establish a bi-directional route between the source and the destination. The Route Error (RERR) message handles the route maintenance and connection failures.

III. Basics of Routing Algebra

In this work, the network is designed with low power wireless nodes. Graph $G(V, E)$ represents the model of the network. Vertices, V, is the set of all low power wireless devices and edges, E, is the set of links that stand for the connectivity between the nodes. An edge is present between two nodes if they are within the transmission range of each other and communication is possible between the two nodes. G is a strongly connected graph. Thus, every node is reachable from every other node through some path in the network.

Routing algebra is formally defined and studied in the literatures [12], [25]–[27], and it is also known as *path weight structure*. The quadruplet $(S, \oplus, \omega, \preceq)$ represents the routing tuple, where, S represents the set of all paths in the network, ω represents the function that maps a path to the weight, and $\oplus$ represents the concatenation operator used for two paths in the network [12]. The fourth element $\preceq$ represents the ordered relation between the paths $p, q \in S$; $\omega(p) \preceq \omega(q)$ means that the path p is lighter than the path q and $\omega(p) \prec \omega(q)$ means p is strictly lighter than q. Here, the lighter route is taken as a better route for routing option.

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The optimality, loop-freeness, and consistency are the three essential requirements to ensure a routing protocol is usable. $R(s,d)$ represents the path converged by the routing protocol. A weight structure with route $R(s,d) = p =< s, v_1, v_2, ..., v_{n-1}, v_n, d >$ between the source s and the destination d is consistent if all the intermediate nodes choose the same path to destination d, then, $R(v_i, d) =< v_i, v_{i+1}, v_{i+2}, ..., v_n, d >, \forall v_i \in p$. A path $r =< v_1, v_2, ..., v_{n-1}, v_n >$ is loop-free if $v_i \neq v_j \forall\ i \neq j$. A path structure for a routing protocol, R, is optimal if it finds the lightest path from all the paths between two pair of nodes $(s, d) \in V$. That is, $R(s,d) \preceq p_{s.d}$ where $p_{s,d}$ is any non-empty path between the nodes s and d. This also ensures lightness of the route.

Isotonicity and monotonicity are the two properties of path weight structure. A routing metric must satisfy these two properties to ensure the optimality, loop-freeness, and consistency of the routing protocol. Isotonicity and monotonicity are defined as follows [12]:

> The quadruplet $(S, \oplus, \omega, \preceq)$ is **isotonic** if $\omega(p) \preceq \omega(q)$ implies both $\omega(p \oplus r) \preceq \omega(q \oplus r)$ and $\omega(s \oplus p) \preceq \omega(s \oplus q) \forall\ p, q, r, s \in S$. And, $(S, \oplus, \omega, \preceq)$ is **strictly isotonic** if $\omega(p) \prec \omega(q)$ implies both $\omega(p \oplus r) \prec \omega(q \oplus r)$ and $\omega(s \oplus p) \prec \omega(s \oplus q) \forall\ p, q, r, s \in S$.
>
> The quadruplet $(S, \oplus, \omega, \preceq)$ is **monotonic** if $\omega(p) \preceq \omega(p \oplus q)$ and $\omega(p) \preceq \omega(r \oplus p)$ holds $\forall\ p, q, r \in S$. And, $(S, \oplus, \omega, \preceq)$ is **strictly monotonic** if $\omega(p) \prec \omega(p \oplus q)$ and $\omega(p) \prec \omega(r \oplus p)$ holds $\forall\ p, q, r \in S$.

Isotonicity implies that the order relation will not be affected by prefixing or suffixing a third route. Isotonicity ensures that the path formulated by the routing protocol is optimal and strict optimality ensures the path is consistent. Monotonicity means that the path will not get lighter by prefixing or suffixing another path to it. Monotonicity ensures that the path found using the routing protocol is loop free.

IV. Route Metric for LOADng

In this section, we define the routing metric in two stages. The first stage defines the Remaining Energy (RE) metric and the Live Route (LR) metrics. The second stage is to establish a composite metric called $LR + RE$ and it is designed based on RE, LR, and HC. The RE metric is a ratio of the initial energy and the residual energy of the node.

$$RE = \frac{E_i}{E_{re}} \tag{1}$$

where E_i is taken as the initial energy, and E_{re} is the residual energy of the node. The value of RE increases slowly until residual energy reaches 10% and then increases rapidly after residual energy is less than 10%. This increment in RE will enable the routing protocol to avoid low energy nodes during the route discovery phase.

The LR metric counts the number of active connections through the node and the value of LR can be taken from the nodes routing table.

$$LR = routingTable.GetActiveRouteCount \tag{2}$$

While identifying the existing route from the routing table, any loopback addresses are to be avoided and all interfaces of the node are to be accounted for. Active number of connections per node indicates the traffic congestion through the node. As the value of LR increases for a node, the traffic congestion increases and can lead to dropping of packets. Choosing LR route metric can improve the packet delivery ratio by reducing the packet drop due to traffic congestion at a node.

A composite metric, $LR + RE$ is proposed by combining the RE, LR and HC metrics. Equation 3 gives the $LR+RE$ metrics for the node n.

$$\begin{aligned} &\omega(n) = \alpha RE_n + \beta LR_n + \gamma HC \\ &or, \\ &\omega(n) = \alpha\omega_1(n) + \beta\omega_2(n) + \gamma\omega_3(n) \end{aligned} \tag{3}$$

where, RE_n is the ratio of Remaining Energy of the node n, LR_n is the active connections through the node n, HC is the hop count (equal to 1) and provides the minimum hop increment, and α, β, and γ are the tuning factors for RE_n, LR_n, and HC respectively. The route cost is the sum of the hop costs over all nodes along the path.

$$\omega(p) = \sum_{n \in p} \omega(n) \tag{4}$$

Minimum increment (HC) is necessary to ensure a minimum increase in the route cost when a node is added to the path to the destination. The choice of α and β depends on the application. When $\alpha = 0$ and $\beta = 0$, the routing protocol works like the traditional LOADng routing protocol. When $\alpha = 1$ and $\beta = 0$ LOADng works with RE as the routing metric and $\alpha = 0$ and $\beta = 1$ LOADng works with LR as the routing metric. When $\alpha \geq 1$ and $\beta \geq 1$, LOADng routing protocol work with the composite routing metric. $\gamma \geq 1$ is used to ensure there exists a minimum hop cost increment when a new node is added to the existing path and $\omega(n) > 0\ \forall\ n \in V$.

In this work, the concatenation operator $\oplus$ represents an addition of weight calculated by the node to the weight present in the routing packet. Equation 5 defines concatenation operator $\oplus$.

$$\begin{aligned} \omega(p \oplus q) &= \omega(p) + \omega(q) \\ &= \alpha\omega_1(p) + \beta\omega_2(p) + \gamma\omega_3(p) \\ &\quad + \alpha\omega_1(q) + \beta\omega_2(q) + \gamma\omega_3(q) \end{aligned} \tag{5}$$

Ordered relation $\preceq$ means less than of equal to ($\leq$) and Equation 6 defines the ordered relation $\preceq$.

$$\omega(p) \preceq \omega(q) \cong \omega(p) \leq \omega(q) \tag{6}$$

The proposed composite routing metric ($LR + RE$) is additive and should hold the two properties: isotonicity and monotonicity.

Theorem The $LR + RE$ composite routing metric is isotononic.

Proof: Since we add the minimum hop increment $HC = 1$

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with $\gamma \geq 1$, $\omega(p) > 0$ and $r \in S$ is a non empty path. Then,

$$\begin{aligned}\omega(p) \preceq \omega(q) &\Rightarrow \omega(p) + \omega(r) \preceq \omega(q) + \omega(r)\\ &\Rightarrow \alpha\omega_1(p) + \beta\omega_2(p) + \gamma\omega_3(p)\\ &+ \alpha\omega_1(r) + \beta\omega_2(r) + \gamma\omega_3(r) \preceq\\ &\alpha\omega_1(q) + \beta\omega_2(q) + \gamma\omega_3(q)\\ &+ \alpha\omega_1(r) + \beta\omega_2(r) + \gamma\omega_3(r)\\ &\Rightarrow \omega(p \oplus r) \preceq \omega(q \oplus r) \quad \{from\ Eqn.\ 5\}\\ and,&\\ \omega(p) \preceq \omega(q) &\Rightarrow \omega(r) + \omega(p) \preceq \omega(r) + \omega(q)\\ &\Rightarrow \alpha\omega_1(r) + \beta\omega_2(r) + \gamma\omega_3(r)\\ &+ \alpha\omega_1(p) + \beta\omega_2(p) + \gamma\omega_3(p) \preceq\\ &\alpha\omega_1(r) + \beta\omega_2(r) + \gamma\omega_3(r)\\ &+ \alpha\omega_1(q) + \beta\omega_2(q) + \gamma\omega_3(q)\\ &\Rightarrow \omega(r \oplus p) \preceq \omega(r \oplus q) \quad \{from\ Eqn.\ 5\}\end{aligned}$$

$\Rightarrow metric\ is\ Isotonic$

Since $\omega(p) > 0$, the above statements are valid for $\omega(p) \prec \omega(q)$ as well. Hence, $LR + RE$ metric is strictly isotonic.

Theorem The composite routing metrics proposed is monotonic.

Proof: Since we add the minimum hop increment $HC = 1$ with $\gamma \geq 1$, $\omega(p) > 0$ and $r \in S$ is a non empty path. Then,

$$\begin{aligned}&\omega(p) \preceq \omega(p \oplus r)\\ &\Rightarrow \omega(p) \preceq \alpha\omega_1(p) + \beta\omega_2(p) + \gamma\omega_3(p)\\ &\qquad + \alpha\omega_1(r) + \beta\omega_2(r) + \gamma\omega_3(r)\ \{from\ Eqn.\ 5\}\\ &\Rightarrow \omega(p) \preceq \omega(p) + \omega(r)\\ &since,\ we\ know\ \omega(p) > 0\ and\ \omega(r) > 0,\\ &the\ metric\ is\ right\ monotonic.and,\\ &\omega(p) \preceq \omega(r \oplus p)\\ &\Rightarrow \omega(p) \preceq \alpha\omega_1(r) + \beta\omega_2(r) + \gamma\omega_3(r)\\ &\qquad + \alpha\omega_1(p) + \beta\omega_2(p) + \gamma\omega_3(p)\ \{from\ Eqn.\ 5\}\\ &\Rightarrow \omega(p) \preceq \omega(r) + \omega(p)\\ &since,\ we\ know\ \omega(p) > 0\ and\ \omega(r) > 0,\\ &the\ metric\ is\ left\ monotonic.\\ &\Rightarrow metric\ is\ Monotonic.\end{aligned}$$

Since $\omega(p) > 0$, the above statements are valid for $\omega(p) \prec \omega(p \oplus r)$ as well and hence, $(LR + RE)$ composite metric is strictly monotonic. Thus, the proposed routing metric satisfies the two properties and it is a suitable candidate for LOADng routing protocol.

LOADng routing protocol is designed to use the $LR+RE$ composite routing metric instead of hop count as its metric. Figure 1 shows the route update rules while processing its route discovery messages.

Algorithm 1 Route Update Rule - LOADng

```
dst := packct_destination;
seqNum := packet_sequence_number;
HC := 1;
RE := node_ResidualEnegry;
LR := node_ActiveRoutes;
nodeCost := α ∗ RE + β ∗ LR + γ ∗ HC;
routeCost := packet_routeCost + nodeCost;
hopCount := packet_hopCount + HC
route := routingT ableEntry(dst); /* Get the routing table entry
                                      for destination*/
if route = N U LL then
   route_seqNum := seqNum;
   route_hopCount := hopCount;
   route_routeCost := routeCost;
   insert(dst, route)
else if route_seqNum < seqNum ||
 (route_seqNum = seqNum && route_routeCost < routeCost) ||
 route_seqNum = seqNum && route_routeCost =routeCost &&
       route_hopCount < hopCount)
then
   route_seqNum := seqNum;
   route_hopCount := hopCount;
   route_routeCost := routeCost;
   update(dst, route)
end if
```

Figure 1. Route Update Rule - LOADng

V. NUMERICAL RESULTS AND DISCUSSIONS

LOADng routing protocol with the proposed metric was implemented and simulated in Network Simulator 3 (NS3). Initially, LOADng protocol was developed using the traditional Hop Count metric and then it was modified to incorporate the composite metric. The results obtained are compared with HC, RE, and LR as the primary metrics for LOADng routing protocol. The packet drop, packet delivery ratio (PDR), the maximum residual energy of any node after the network dies, the energy wastage of the network and the network lifetime are analyzed and compared. The simulation is allowed to run until any of its nodes run out of battery. Network lifetime is taken as the time at which the first node in the network dies off. All values are computed with the assumption that the network is homogeneous, and all nodes start with the same initial energy. The network is uniformly distributed with constant node density. Random traffic is generated between two distinct pairs of nodes where 15% of the nodes are active sources. The paper does not consider mobility and consider all nodes in network static.

Figure 2 shows the percentage of packet dropped versus the total number of nodes in the network. The packet drop over the traditional LOADng with HC route metric is higher compared to the other three options. The LOADng with LR metric performs better than the RE and HC, as the LR metric is capable of identifying the congested nodes in the network and avoid them whenever possible. However, when using $LR + RE$, the packet drop was further reduced. The reduction in the percentage of packet dropped is owing to the ability of

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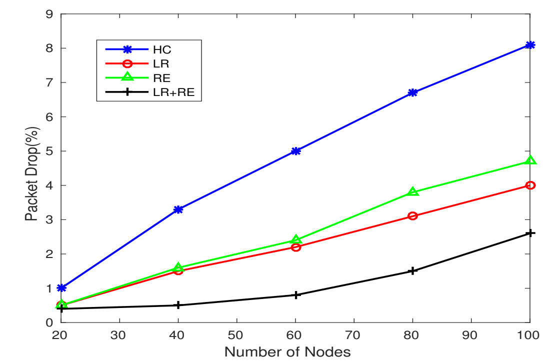

Figure 2. Percentage of Packet Drop

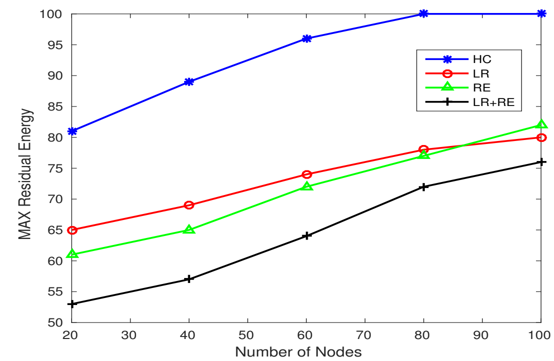

Figure 4. Maximum Residual Energy

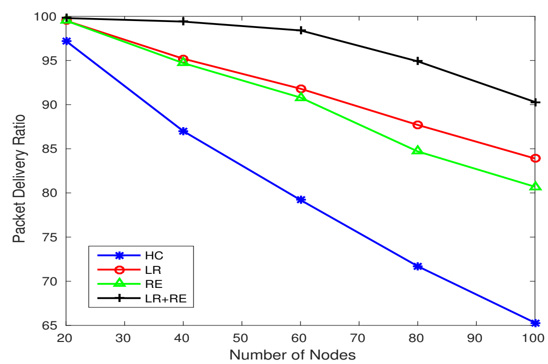

Figure 3. Packet Delivery Ratio

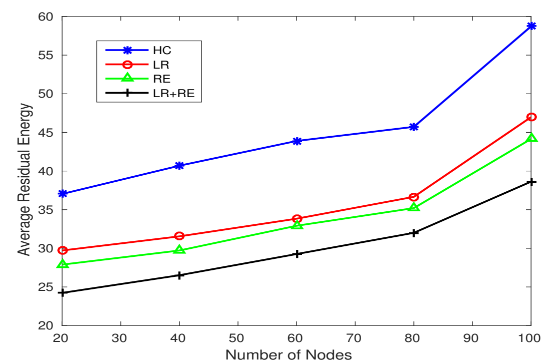

Figure 5. Average Residual Energy

$LR + RE$ to identify the congested node and nodes with low energy and avoid them as much as possible.

The direct consequence of the reduction in percentage packet drop is the improvement in the PDR. Figure 3 shows the PDR versus the number of nodes in the network. PDR decreases when the number of nodes in the network increase and the number of hops required to reach the destination increases. HC has the lowest PDR compared to other three metrics. HC only considers the shortest path towards the destination. PDR is better for the LR metric in comparison to the RE metric. $LR + RE$ outperforms all the other metrics under consideration.

Energy wastage is also a significant concern in a low power network. Energy wastage is the amount of energy remaining in the node after the network reaches its lifetime. Routing protocol should distribute the energy consumption to ensure the minimum energy wastage. Reduced energy wastage also shows the ability of the protocol to distribute the load within the network in a fair manner.

$$E_{max\_residual\_energy} = max(v_i(E_{re}) : \forall v_i \in V) \quad (7)$$

where, $v_i(E_{re})$ is the residual energy of node v_i.

Figure 4 shows the maximum residual energy of some node after the network reaches its lifetime. The corner node in the network remains largely unused in case of the traditional LOADng routing protocol. Thus, the HC metric does not distribute the load in an efficient manner. The RE metric shows a better distribution than LR. However, as the number of nodes in the network grows the routing protocol with LR metric surpasses the performance of RE metric. $LR + RE$ takes the advantage of both LR and RE. The maximum residual energy by any node in the network is lowest for $LR + RE$.

The average residual energy of the network is computed using the Equation 8.

$$E_{net_avg} = \frac{\sum_{i=1}^{N}(v_i(E_{re}))}{N} \quad (8)$$

where N is the total number of nodes in the network.

Simulation results show that the energy distribution of RE metric is better than LR metric. $LR + RE$ has the lowest average network energy. Here, the low values of E_{net_avg} indicate even distribution of the load and reduced energy wastage. This scenario satisfies the primary requirement of LLNs with energy constrained devices. Figure 5 shows the comparison of E_{net_avg} for different metrics.

The network lifetime comparison is given in Figure 6. LOADng with HC metric has the lowest lifetime because it fails to address congestion and energy constraints of the node. Network lifetime of RE metric is better than LR metric as RE metric addresses the energy constraints of the node. The composite metric $LR + RE$ gives the best performance out of all metrics under consideration. $LR + RE$ shows an initial improvement in the network lifetime when the number of nodes in the network is 40. This improvement is attributed to

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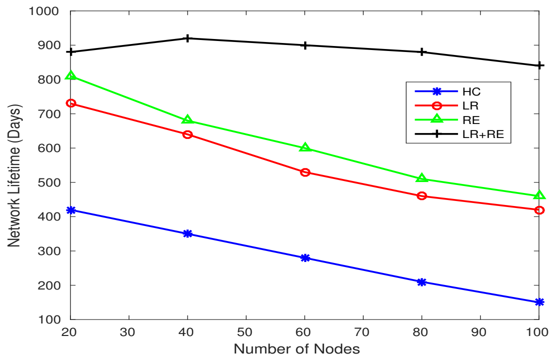

Figure 6. Network Lifetime

higher number of the nodes, and hence more path options available. The network lifetime decreases as the number of nodes increases because the hop distance between the source and destination also has increased. LOADng routing protocol with composite routing metric, $LR{+}RE$, significantly improves the network lifetime and the PDR compared to the conventional LOADng routing protocol with HC as the routing metrics.

VI. Conclusion and Future Works

In this paper, we consider routing metrics design for LLNs to support machine to machine communication in IoT. The LOADng routing protocol supports point to point communication in a network with sparse traffic. A composite routing metric $LR + RE$ is proposed in this paper which combines the remaining energy and the number of active routes through the node. The packet drop, packet delivery ratio, the maximum energy of any node after the network dies, the energy wastage of the network and the network life are analyzed and compared. The results obtained through simulation show that using composite metric $LR + RE$ with LOADng routing protocol can significantly improve the performance of LLNs with energy constrained devices with sparse traffic. As a future work, we propose to incorporate link quality metrics to improve QoS requirements of the network.

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