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Performance Analysis of Routing Metrics for Wireless Sensor Networks

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ABSTRACT: *A wireless sensor network is a heterogeneous network consisting of a large number of tiny low-cost nodes and one or more base stations. Each sensor node comprises sensing, processing, transmission, mobilize, position finding system, and power units. These networks can use in various applications like military, health and commercial. Routing in wireless sensor networks has been an active area of research for many years. Sensor nodes have a limited transmission range, processing, storage capabilities and energy resources are also limited. In wireless sensor networks data is forwarded using multi-hop mechanism. Therefore, a variety of routing metrics has been proposed by various authors in wireless sensor networks for providing routing algorithms with high flexibility in the selection of best path and offering a compromise between throughput, end-to-end delay, and energy consumption. In this paper, we present a detailed survey about existing routing metrics in wireless sensor networks. The routing metrics are also compared based on their essential characteristics and tabulated.*

Keywords: *WCETT, ETT, ETX, Hopcount, RTT, MIC*

I. INTRODUCTION

A wireless sensor network (WSN) is a heterogeneous network consisting of a large number of tiny low-cost nodes (devices) and one or more base stations (sinks). Main purpose of the WSN is to monitor some physical phenomena (e.g., temperature, barometric pressure, light) inside an area of deployment. Nodes are equipped with radio transceiver, processing unit, battery and sensor(s). Nodes are constrained in processing power and energy, whereas the base stations are not severely energy resources. The base station act as gateways between the WSN and other networks such as Internet etc.. The WSN is used in various applications like military, health and commercial. They provide simple and cheap mechanism for monitoring in the specified area. WSNs are frequently deployed to collect sensitive information. WSN can be used to monitor the movements of traffic in a city.

Such a network can be used to determine location of people or vehicles [1]. WSNs can be classified according to several aspects with impact on the security protocol design. One such aspect is the mobility of nodes and the base station. The nodes can be mobile or placed on static positions. The same holds true for the base station. Another consideration is the way the nodes are placed. The nodes can be deployed manually on specific locations following some predefined network topology or randomly deployed in an area, e.g., by dropping from a plane. The number of nodes is also a very important factor number of nodes in a network can range from tens to tens of thousands. Because of limited transmission range, communication between any two devices requires collaborating intermediate forwarding network nodes, i.e. devices act as routers to forward the data. Communication between any two nodes may be trivially based on simply flooding the entire network. However, more elaborate routing algorithms are essential for the applicability of such wireless networks, since energy has to be conserved in low powered devices and wireless communication always leads to increased energy consumption.

The rest of the paper is organized as section 2: discuss about various routing metrics, section 3: presents a comparison of routing metrics, section 4: concludes the paper.

II. ROUTING METRICS

The existing routing metrics are classified into five categories based on their operation. Topology based, Signal strength based, Active probing based, Mobility aware and Energy aware metrics.

1.1. Topology Based

In this technique the topological information of the network will be considered i,e. the number of neighbors of each node, number of hops and/or paths towards a particular destination. The metrics always consider connectivity information which is available locally by the routing protocol, without requiring additional passive or active measurements. The topology-based metrics do not take into account several variables that have an impact on both the network and application performance, such as the transmit rates of the links are popular due to their simplicity.

Hop count

In this metric, every link counts as one equal unit independent of the quality or other characteristics of the link and very simple technique. The ease of implementation has made hop count the most widely used metric in wired networks and it is the default metric in many wireless sensor networks routing protocols, such as OLSR [2], DSR [3], DSDV [4] and AODV [5]. Fewer hops on the data path produce smaller delay, whether these involve network links or buffers or computational power. The implicit assumption is the existence of error-free links. On the contrary, links in wireless sensor networks cannot be assumed error-free.

1.2. Signal Strength Based Metrics

Signal strength metric has been used as link quality metrics in several routing protocols for wireless sensor networks. The signal strength can be viewed as a good indicator for measuring link quality since a packet can be transferred successfully when the signal strength is more than the threshold value.

1.3. Active Probing Based Metrics

To overcome the drawbacks of topology based metrics various authors have proposed active probing metrics to carry out active measurements and use probe packets to directly estimate those probabilities. Probing technique had various challenges such as packet sizes of probes in the network should be equal to the data so that what probes measure is as close to the target as possible and probe packets should not give any priority in the network. The probing based metrics have proved promising in the context of wireless sensor networks. They measure directly the quantity of interest, rather than inferring it from indirect measurements, and do not rely on analytical assumptions.

Per-hop Round Trip Time (RTT)

The per-hop Round-Trip Time (RTT) metric is based on the bidirectional delay on a link [6]. In order to measure the RTT, a probe packet is sent periodically to each neighboring node with time stamp. Then each neighbor node returns the probe immediately. This probe response enables the sending node to calculate the RTT value. The path RTT metric is the summation of all links RTT in the route. The RTT metric is dependent on the network traffic. Since it comprises queuing, channel contention, as well as 802.11 MAC retransmission delays.

Per-hop packet pair delay (PktPair)

This delay technique is designed to overcome the problem of distortion of RTT measurements due to queuing delays and it consists periodic transmission of two probe packets with different sizes back-to-back from each node. The neighbor node calculates the inter-probe arrival delay and reports it back to the sender. This metric is less susceptible to self-interference than the RTT metric, but it is not completely immune, as probe packets in multi-hop scenario contend for the wireless channel with data packets. Both the RTT and PktPair metrics measure delay directly, hence they are load-dependent and prone to the self-interference phenomenon. Moreover, the measurement overhead they introduce is $O(n^2)$, where n is the number of nodes.

Expected Transmission Count (ETX)

To overcome drawbacks of RTT and PktPair techniques, authors proposed Expected Transmission Count (ETX) metric which is first routing metric based on active probing measurements designed for wireless sensor networks. ETX estimates the number of transmissions required to send a packet over a link. Minimizing the number of transmissions optimize the overall throughput and energy consumption. Let d_f is the expected forward delivery ratio and d_r is the reverse delivery ratio, Assuming that each attempt to transmit a packet is statistically independent from the precedent attempt, each transmission attempt can be considered a Bernoulli trial and the number of attempts till the packet is successfully received a Geometric variable, the expected number of transmissions is defined as

$$ETX = \frac{1}{d_f \cdot d_r}$$

Expected Transmission Time (ETT), Medium Time Metric (MTM), and Weighted Cumulative Expected Transmission Time (WCETT)

Draves [7] presented the drawbacks of ETX technique such as it prefers heavily congested links to unloaded links, if the link-layer loss rate of congested links is smaller than on the unloaded links. Later he proposed the Expected Transmission Time (ETT) metric incorporating the throughput into its calculation. Let S be the size of the probing packet and B the measured bandwidth of a link, then the ETT of this link is defined as

$$ETT = ETX * \frac{S}{B}$$

Awerbuch [8] proposed Medium Time Metric (MTM) based on overhead, reliability of the link and size of the packet.

$$\tau(l,p) = \frac{overhead(l) + \frac{size(p)}{rate(l)}}{reliability(l)}$$

Where overhead is defined as per-packet overhead of the link that includes control frames, back-off, and fixed headers and reliability is denoted as the fraction of packets delivered successfully over the link.

As wireless sensor networks provide multiple non-overlapping channels, they propose an adaptation of the ETT metric accounting for the use of multiple channels, namely the Weighted Cumulative ETT (WCETT). Let k be the total number of channels of a system, the sum of transmission times over all nodes on channel j is defined as:

$$X_j = \sum_{i \text{ uses channell } j} ETT_i \quad 1 \le j \le k$$

As total path throughput will be dominated by the bottleneck channel, they propose to use a weighted average between the maximum value and the sum of all ETTs.

$$WCETT = (1-\beta) \cdot \sum_{i=1}^{n} ETT_i + \beta \cdot \max_{1 \le j \le k} X_j$$

The main disadvantage of the WCETT metric is that it is not immediately clear if there is an algorithm that can compute the path with the lowest weight in polynomial or less time.

Metric of Interference and Channel switching (MIC)

The Metric of Interference and Channel switching (MIC) [9] considers intra-flow and inter-flow interference problem. The MIC metric of a path p is defined

$$MIC(p) = \frac{1}{N \times \min(ETT)} \sum_{link\, l \in p} IRU_l + \sum_{node\, i \in p} CSC_i$$

where N is the total number of nodes in the network and min(ETT) is the smallest ETT in the network, which can be estimated based on the lowest transmission rate of the wireless cards. The two components of MIC, Interference-aware Re-source Usage (IRU) and Channel Switching Cost (CSC) are defined as:

$$IRU_l = ETT_l \times N_l$$

$$CSC_i = \begin{cases} w_1 & \text{if } CH(prev(i)) \ne CH(i) \\ w_2 & \text{if } CH(prev(i)) = CH(i) \end{cases} \quad 0 \le w_1 \le w_2$$

Multi-Channel Routing Metric (MCR)

Kyasanur and Vaidya [10] extend WCETT by considering the cost of changing channels. Let InterfaceUsage(i) be the fraction of time a switchable interface spends on transmitting on channel *i* and let $p_i(j)$be the probability t used interface is on a different channel when we want to send a packet on channel j. If we assume that the total of the current interface idle time can potentially be used on channel j, we can estimate as $p_s(j)$

$$p_s(j) = \sum_{\forall i \neq j} InterfaceUsage(i)$$

Let SwitchingDelay denote the switching latency of an interface. Then, the cost of using channel j is measured as

$$SC(c_i) = p_s(j) * SwitchingDelay$$

In order to prevent frequent channel switching of the chosen paths, a switching cost is included into the ETT metric, so that the resulting MCR metric becomes

$$MCR = (1-\beta)\cdot\sum_{i=1}^{n}(ETT_i + SC(c_i)) + \beta \cdot \max_{1\le j\le k} X_j$$

Modified ETX (mETX) and effective number of transmissions (ENT)

Koksal and Balakrishnan [11] considered the accuracy of loss estimator function. In certain conditions such as links with low average loss rate but high variability, the estimation capacity of the mean statistic is poor. They propose two alternative statistics for the estimation of required number of transmissions over a link.

Modified ETX (*mETX*), is defined as

$$mETX = \exp(\mu + \frac{1}{2}\sigma^2)$$

where µ is the estimated average packet loss ratio of a link and the variance of this value. Like ETX, mETX is additive over concatenated links.

Effective Number of Transmissions (ENT), is defined as

$$ENT = \exp\left(\mu + 2\delta\sigma^2\right)$$

The δ acts as an additional degree of freedom with respect to mETX and the value of δ depends on the number of subsequent retransmissions, which will cause the link layer protocol to give up a transmission attempt.

1.4. Mobility-Aware Metrics

Mobility-aware metrics selects routes with higher expected life-time to minimize the routing overhead related to route changes and their impact on throughput. The metrics largely use signal strength measurements and their rate of variation to infer the stability of links and routes. The path average degree of association stability, as proposed in the context of associativity based routing (ABR) and the affinity metric defined in [12] and reused by the Route-Lifetime Assessment Based Routing (RABR) protocol in [13].

Link associativity ticks and path average degree of association stability

Sensor nodes transmit beacon packets at fixed time intervals and calculate the received number of probs from their neighbors. These values serve as indicators of the actual stability of the link. Low values of associativity ticks imply mobile nodes in high mobility state, whereas high associativity ticks, beyond some threshold value thrA, are obtained when a mobile node is more stable. The average degree of association stability over route *R*, A_{ave}^R, is estimated as a function of the associativity ticks over all links along the route

$$A_{ave}^R = \frac{1}{n}\sum_{l\in R} \mathbf{1}_{A_l \ge A_{thr}}$$

Link affinity and path stability

The affinity of a link is related to the received power over that link, its rate of change and a threshold, determining whether the link is broken or not. Each node calculates the strength of the signal received over periodically. The signal strength change rate as the average rate of signal strength change as

$$\Delta P = \left(P_e(current) - P_e(previous)\right)/dt$$

The link affinity is determined by

$$a_e = \begin{cases} high, \text{ if } \Delta P_{ave} > 0 \\ (P_{THR} - P_e)/\Delta P_e^{ave}, \text{ if } \Delta P_{ave} < 0 \end{cases}$$

The affinity between two nodes A and B is then given by

$$\eta_{AB} = \min[a_{AB}, a_{BA}]$$

The route stability is then given by the minimum of the affinities of all links lying in the route

$$\eta_R = \min_{l\in R} n_l$$

The route is selected as long as the estimated value for its stability exceeds the required time to transfer data, whose estimate equals the time required to transmit data over the link capacity *C*.

Mobility-model driven metrics

Mcdonald and Znati [14] proposed mobility-model driven metric, which defines a probabilistic measure of the availability of links that are subject to link failures caused by node mobility. Each node is characterized by statistical distribution of the mean, variance of the speed of a node and average interval time. Gerharz et al. [15] and Jiang et al. [16] proposed metric based on the estimation of average residual lifetime of a link. However, the weak link in all these studies is the assumption that all nodes have similar mobility characteristics which is not acceptable in wireless sensor networks.

1.5. Energy-Aware Metrics

Energy consumption is an important constraint in wireless sensor networks. Sensors have restricted battery lifetime and are most vulnerable to the energy constraints. In some cases, choosing paths so that the overall delay is minimized may result in overuse of certain nodes in the network and premature exhaustion of their battery. Therefore, energy concerns have to be properly reflected in the definition of routing metrics. The total energy consumed when sending and receiving a packet is influenced by various factors such as the wireless radio propagation environment, interference from simultaneous transmissions, MAC protocol operation, and routing algorithm. The aim objective of energy aware metrics is to minimize overall energy consumption and to maximize the time until the first node runs out of energy.

Minimal Total Power routing (MTPR)

K. Scott [17] proposed Minimal Total Power Routing metric MTPR to minimize the overall energy consumption. Later Singh [18] formalize this idea. Let $e_{i,j}$ denote the energy consumed for transferring a packet from node i to the neighboring node j. Then, if the packet has to traverse the path p, including nodes $n_1.....n_k$, the total energy E required for the packet transfer is

$$E = \sum_{i=1}^{k-1} e_{n_i,n_{i+1}}$$

Minimum battery cost routing (MBCR)

In this metric the battery capacity of a node is taken into consideration to balance the energy consumption over all nodes in a network. The "Minimum Battery Cost Routing" (MBCR) [18] is based on the remaining battery capacity of the node. The ratio of battery capacity R_{brc} is defined as

$$R_{brc} = \frac{E_i}{E_{max}} = \frac{\text{Battery remaining capacity}}{\text{Battery full capacity}}$$

Under the assumption that all nodes have the same battery full capacity, a cost value $f_i(E_i)$ is assigned to each node n_i based on its residual battery capacity E_i

$$f_i(E_i) = \frac{1}{E_i}$$

Then the total available battery lifetime along a path p is the sum of the battery capacities of all nodes along the route

$$R_{bcr}^{p} = \sum_{n_i \in p} f_i(E_i)$$

Out of the full set *P* of possible paths, the one selected p' features minimum total residual battery capacity

$$p' = \{p \in P \mid R_{bcr}^{p} > R_{bcr}^{q}, \forall q \in P\}$$

The aim drawback of MBCR is that the selected route may well feature individual nodes with small remaining battery capacity.

Min-Max Battery Cost Routing (MMBCR)

The Min-Max Battery Cost Routing (MMBCR) metric [19] addresses the drawbacks of MCBR metric in avoiding nodes with very low residual battery capacity along paths with high overall battery capacity. The idea is to select a path, which minimizes the maximum power required at any node in a network. The MMCBR the chosen path must p' fulfill

$$p' = \min_{p \in P} \max_{n_i \in p} f_i(E_i)$$

Conditional max-min battery capacity routing (CMMBCR)

Toh [20] combines the MTPR and MMBCR into one single hybrid routing metric called Conditional Max-Min Battery Capacity Routing (CMMBCR) metric. It searches paths using MTPR, with the restriction that all nodes need to have a remaining percentage battery capacity that exceeds a threshold value γ. If there is no such path then MMBCR is used.

Later Kim [21] compares MTPR, MMBCR and CMMBCR. He presented the overhearing transmissions of some neighboring nodes have a significant impact on the performance of each metric and all behave similarly. In dense networks MTPR allows connections to live longer, whereas in sparse networks it is more important to avoid network partition hence MMBCR performs better.

Maximal residual energy path routing (MREP)

Chang and Tassiulas [22] proposed Maximum Residual Energy Path (MREP) link metric based on the remaining battery capacity and the necessary transmission energy. Let $e_{i,j}$ be the energy consumed to send one packet over the link from node *i* to node *j*, E_j the initial battery energy and E'_j the residual energy at node *j*. Chang and Tassiulas define two metrics for the link i to j. The remaining energy of a node $d_{i,j}$, defined as

$$d_{i,j} = \frac{1}{E_j - e_{i,j}}$$

and the inverse of the residual capacity of a node in terms of packets that can be delivered with the remaining energy

$$d_{i,j} = \frac{e_{i,j}}{E_j}$$

2. Comparison of Routing Metrics

The various metrics are compared based on important parameters and tabulated below table 1.

Table 1: comparison of routing metrics

Metrics	Optimization Objectives	Metric Computation Method	Path Metric Function
Topology based	Minimize delay	Use of locally available information	Summation
Signal strength based	Higher expected route life time	Use of locally available information	Based on routing algorithm
Active probing based	Minimize delay Minimize probability of data delivery	Active probing	Summation
Mobility aware	Higher expected route lifetime	Active probing Metrics piggybacked to route discovery packets	Based on the routing algorithm
Energy aware	Minimize energy consumption	Use of locally available information	Summation

III. CONCLUSION

A wireless sensor network is a heterogeneous network consisting of a large number of tiny low-cost nodes and one or more base stations. These networks can use in various applications like military, health and commercial. Routing in wireless sensor networks has been an active area of research for many years. Sensor nodes have a limited transmission range, processing, storage capabilities and energy resources are also limited. In this paper, we presented a detailed survey about existing routing metrics in wireless sensor networks. The routing metrics are also compared based on their essential characteristics and tabulated. As sensor nodes have limited battery capability energy aware routing metrics are useful.

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