

METRICS IN ROUTING PROTOCOL FOR WIRELESS MESH NETWORKS

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Abstract. The interest in services offered by wireless network has been growing for many years. It has encouraged the development of wireless technologies. New solutions are able to satisfy the ever-increasing demands concerning wireless services. It is also evident in the diversification of quality assessment methods employed with reference to connections used in such networks. One of the basic elements used in connection quality assessment are metrics. The use of metrics is directly linked to the type of the routing protocol applied in a given network. The selection of a given routing protocol is often determined by its specific properties that might be advantageous in a certain network type, or that are important in terms of the type or scope of services provided. Therefore, it is easy to identify a relationship between metrics and the area of application of a given routing protocol. The significance and diversity of metrics is also reflected in Wireless Mesh Networks (WMNs). The proposed paper presents a review of the current state-of-the-art routing metrics for Ad-hoc and WMN networks.

1 Introduction

The wireless mesh networks technology has become more and more common and widely used [18, 11, 12, 3, 24] over the past few years. Recently, networks of this type have undergone a significant evolution and are now a very promising technology that can provide answer to many problems related to broadband access to networks [11, 12].

Wireless Mesh Networks (WMNs) can easily, effectively and in wireless mode connect whole cities and towns using inexpensive already existing technologies. Traditional networks are based on a low number of wired or wireless access points that guarantee communication between users of a network, whereas in wireless mesh networks the network connection is distributed between tens or even hundreds of wireless mesh nodes that communicate with one another to make a network connection available in a large area.

Wireless mesh networks are still a dynamic domain that is constantly growing, though a considerable number of issues related to protocols and routing metrics is still open [14]. It turns out that the the hitherto wide use of protocols and metrics derived from the Ad-Hoc network

is ineffective due to different network characteristics that do not meet all the requirements that apply to mesh networks, which results in a situation where all advantages of the mesh network cannot be fully utilized [20].

This article aims to provide a comparative analysis of routing metrics that are used in WMN networks. The article has been structured into four sections. Section 2 presents a general outline of the WMN network architecture and the potential application of the network of this type. Section 3 includes a description of the metrics used for routing protocols in WMN that follows a brief outline of some basic information on metrics. The most important conclusions that can be drawn from the carried out analysis are presented in Section 4.

2 Characteristics of WMN

WMN networks connect stationary and mobile users and can offer access to the Internet network. As compared to the Ad-Hoc network, network nodes are not mobile or are mobile to a lesser extent and offer users access to the network while omitting constraints specifically characterizing Ad-Hoc networks, such as limited energy resources or significant relocation of nodes (nodes mobility). In effect, WMN users can be both mobile and stationary, and can be added to the network through radio or wired links (Fig. 1).

WMN networks have many advantages including the following most important advantages:

- fast and easy expansion (enhancement) of the system - the biggest advantage of wireless mesh networks, as compared to traditional wired and wireless networks, is that they are really wireless. The bulk of traditional wireless access points must be in fact connected to the Internet to guarantee access for their users. In mesh networks only a number of selected nodes has physical connection to the Internet, while the remaining nodes are based exclusively on wireless connec-

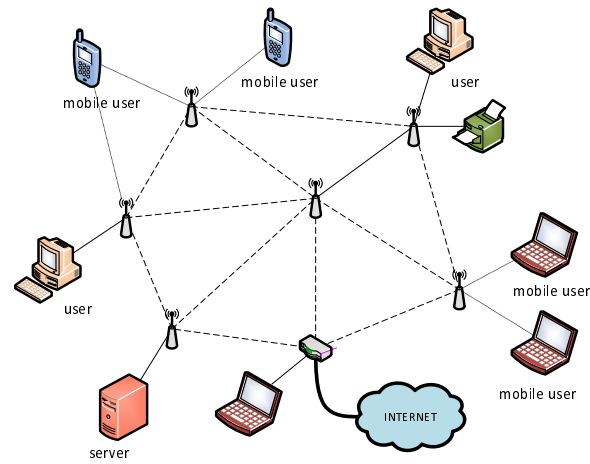


Fig. 1: WMN network architecture

tions to other nodes. What is important, any extension (enhancement) of an existing network of this type requires a lower number of links, which translates into lower financial outlays and shorter time of their execution

- self-configuration of nodes in the network - the very nature of the WMN network allows for newly created nodes to be automatically added without any necessity to perform any additional works by the network administrator,
- self-healing capability - due to its topology and the nature of the network of this type, failures of single nodes are not followed by a failure of the whole of the network; routing paths are set up automatically, without any involvement of damaged nodes, by way of alternative paths,
- large territorial range - with the limitations such as necessary cabling for a WMN network, they are virtually unlimited in their territorial range, the only constraining criterion being the number of installed nodes of the network. At the same time, installation of new nodes is easy and relatively inexpensive, which is an additional asset of the WMN network.

Because of the relative simplicity of the construction of mesh networks, their relatively low costs, self-configuration and the capacity of self-healing in the mesh topology, more and more manufacturers implement solutions that make this technology easily implemented. Regrettably, no relevant standards have been developed as yet and hence these solutions are most frequently incompatible with one another.

WMN networks can be used to service different types of applications, starting from the basic access to the Internet network (the last mile problem), through applications of CCTV monitoring and mass events security, to solutions for the military to be applied in communication service, including communication in field of combat.

In the initial stage of the development of WMN networks attempts were made to adapt existing routing protocols and metrics used in Ad-Hoc networks. Soon it was clear, however, that a development of protocols specifically dedicated to mesh networks was a necessity. The protocols are to include particular features of such networks. Changes should be also administered to metrics that are used in routing protocols. The fact that the metrics known from protocols for Ad-Hoc networks cannot be applied for WMN networks is a significant hampering factor in the designing and development of new protocols. Eventually, a number of metrics specifically designed for WMN networks that can be used by new or modified routing protocols have been proposed.

3 Routing metrics

3.1 Introduction

Metrics are the key elements of the routing process. In most general terms, the metric is a set of properties for a route/path that is composed of any possible values that are essential and used by routing protocols for a selection of the optimum route. In WMN networks, due to their specificity, it is necessary to apply dedicated metrics that take

into account particular features specific to these networks. Routing metrics, according to the properties that they take into account, can be divided as follows:

- metrics related to the number of hops (Hop Count),
- metrics that are aware of capacities of links,
- metrics that determine the quality of a connection (Link Quality Metrics),
- metrics that take into consideration diversity of transmission channels,
- metrics that are aware of interferences either intra or inter flow.

Another division, related rather to potential applications for the purposes of which metrics can be used is proposed by the authors of [15]:

- topology based metrics,
- use of active probing measurements metrics,
- energy-aware metrics,
- mobility-aware metrics,
- receiving signal strength based metrics.

Yet another, more general, division is to be found in [13]. The authors have grouped metrics into four sub-groups according to the main parameters that the considered metrics include:

- simple metrics,
- interference aware metrics,
- load aware metrics,
- interference and load aware metrics.

By examining the literature of the subject one can encounter some other divisions introduced by researchers. However, one can come to a conclusion that they are of

rather conventional character and do not represent any standard, being just supporting in systematizing metrics for the purposes of particular publications and being just proposals of their authors. What is even more, there are routing metrics that do not fit into any of the earlier categories or, conversely, they apply to more than just one of them [15].

Regardless of a categorization of metrics and the properties that they take into consideration there are certain critical conditions that they are to satisfy. Firstly, while being used by routing protocols, they must guarantee route stability and, what is more, these routes should offer the best possible efficiency parameters within the context of the selected properties (e.g. the number of hops, quality parameters of the link, interference, etc.). It should not be forgotten that the calculation of the values of metrics should be performed with minimum computational complexity that, however, should not influence in any way the quality of obtained results. Last but not least criterion for the evaluation is to guarantee appropriate mechanisms that would prevent loops in determined routes (loop-free mechanism).

According to the requirements that are to be met by metrics, the process of their development must be subjected to optimization operations that are targeted at:

- minimization of delays,
- increase in the probability of data delivery,
- maximization of the global throughput (flow capacity) for the path,
- equalization of the load,
- minimization of energy consumption.

Routing metrics can be calculated differently. The same applies to the way data used for these calculation are retrieved. A considerable group of metrics is a group of active probing based metrics in which additional data packets are transmitted between nodes of the network.

These packets serve to measure necessary properties of a link/route. Other methods include:

- passive monitoring – calculation of metrics is carried out on the basis of the values related to normal traffic in the network,
- using locally available data – metrics are calculated only on the basis of data available in a given node of the network,
- piggyback probing – metrics are calculated on the basis of measurement information delivered along with normal traffic.

Having calculated metrics for particular links between nodes, it is necessary to determine routing metrics for the whole connection path (from the source to the destination node). Route metrics are usually calculated by a summation or multiplication of link metrics.

3.2 Review of routing metrics

The routing metrics in WMN has been divided into specific categories according to their distinctive features: Hop Count Metrics, Active-probing Metrics, Energy-aware Metrics and Signal strength Metrics. The following sections present a description of existing metrics with their respective characteristic features.

3.2.1 Topology based metrics

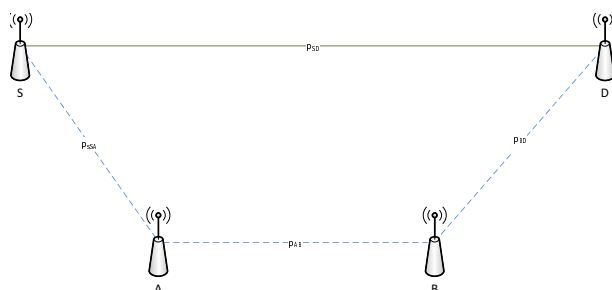


Fig. 2: Hop Count Metric

Hop count Hop count is one of the most frequently used routing metrics and finds its application in most commonly used wireless routing protocols [5] and in traditional routing protocols for wired networks. For the evaluation of the path quality this metric uses the number of hops between the source and the destination (target). The only quality parameter is the existence, or the absence, of a routing path between two nodes in the network. Additionally, the assumption is that the existing paths have no errors (Fig. 2). The most important advantage of this metric is its simplicity and the resulting easy implementation. The main disadvantage of the Hop count metric is the lack of a possibility to take account of any parameters of quality of chosen routing paths like throughput, packet loss rate, or interferences.

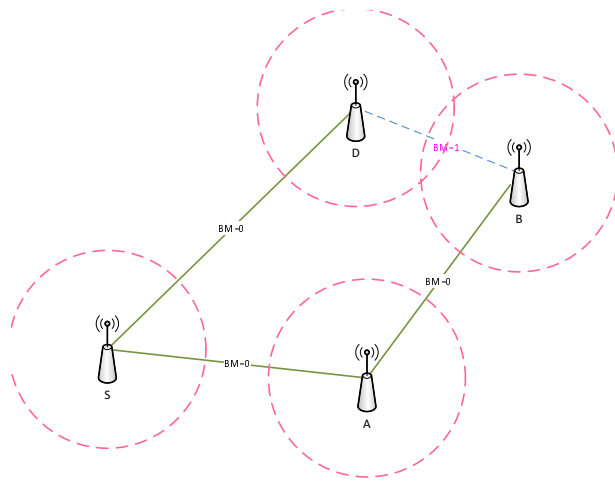


Fig. 3: Blocking Metric

Blocking metric Blocking Metric is a modification of the earlier metric that aims at the inclusion of selected parameters of Blocking Value (BV). Here, Blocking Value can be treated as a parameter that defines the quality of paths or links. The BV parameter corresponds to the number of nodes that interfere with the node for which the metric is being calculated. One can assume then that in this way a combination of the simplicity of the Hop Count

metric determination with the inclusion of interference to transmission that occurs between adjacent nodes has been achieved (Fig. 3). The metric for paths can be determined by a summation of Hop Count metrics in single links. Having the knowledge of the Hop Count path metrics it is possible to choose such a path for which Blocking Value is as low as possible. A disadvantage to thus defined metric is, however, the lack of possibility to take into account the differences between transmission rates and the level of packet loss rate.

3.2.2 Active Probing Based Metrics

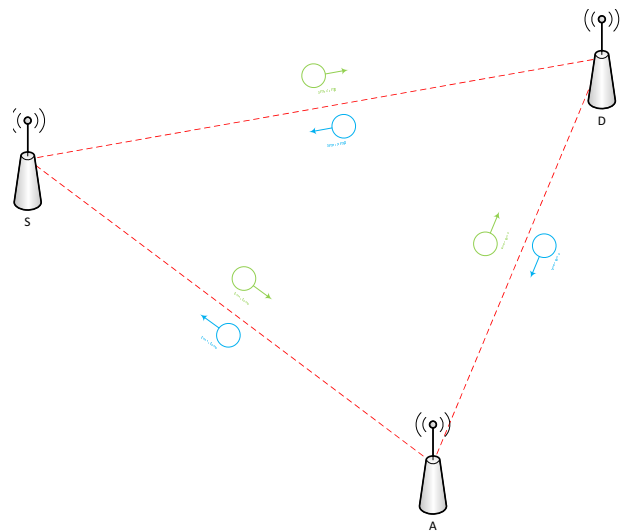


Fig. 4: Per-Hop Round Trip Time Metric

Per-Hop Round Trip Time (RTT) According to [1] the Per-Hop Round Trip Time (RTT) metric is calculated as the time that has elapsed from the beginning of the instance of sending a data probe to the instance of the acknowledgement of receipt from a destination node. Regularly, this calculation is based on many values retrieved recurrently on the basis of which the average value is calculated. The preferred path is a path for which the sum of all RTT values for the links between successive nodes is the lowest (Fig. 4). The advantages of the RTT metric include: its dependence on current traffic, queueing process

and on potential retransmissions taking place in the MAC layer. The metric's disadvantages include, for example, averaging of the metric value. This means that the total weight is based on the average value of RTT in individual nodes, while this can in consequence lead to a choice of a path that is composed of links with low quality. The metric calculation process generates additional probe-related overhead.

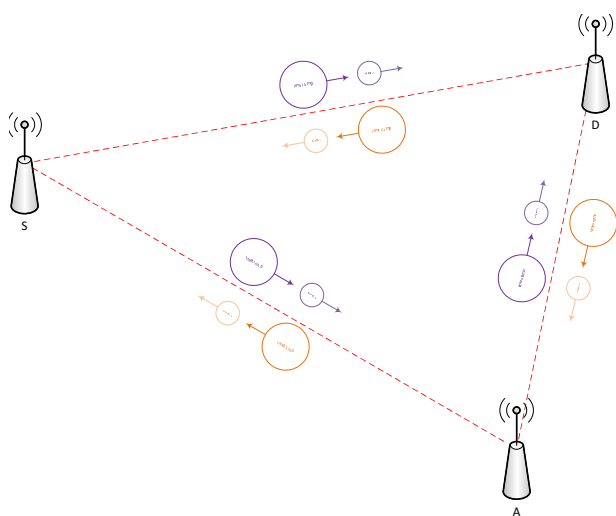


Fig. 5: Per-hop Packet Pair Delay Metric

Per-hop Packet Pair Delay (PktPair) The metric proposed in [6] is based, as in the case of the metric described above, on a calculation of the time required to reach the destination and to receive the acknowledgement of receipt sent by the sending node. However, a significant modification has been introduced that is aimed to take into account packet sizes in the calculation of the metric. Packets are sent in a sequence - first, a small data packet, then the other large one (Fig. 5). The destination node calculates how long it will take both packets to reach the destination from the source (delays) and sends back the information to the sender. This method provides an opportunity to make the value of the metric dependent on the load of a link and delays related to the queuing process more accurately. Exactly as in RTT, this metric takes into account

losses and delays caused by retransmissions and channel contention. A disadvantage, however, is its even bigger overhead (as compared to RTT) that is caused by the instances of sending not just one probe but two.

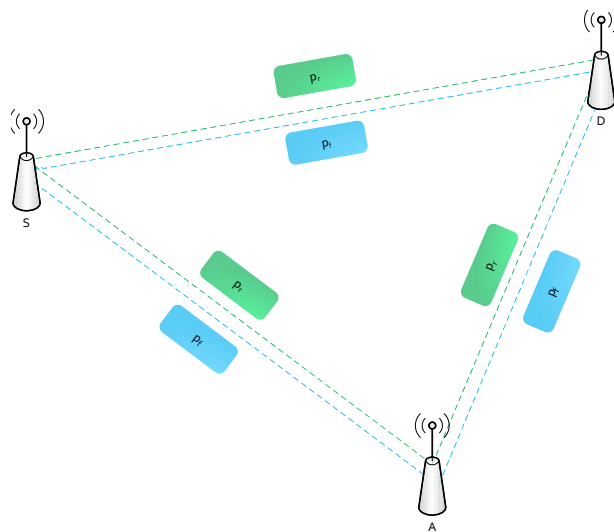


Fig. 6: Expected Transmission Count Metric

Expected Transmission Count (ETX) The Expected Transmission Count (ETX) metric is proposed in [7]. ETX is an improved version of the Hop Count metric that takes into account both the length of the routing path (the number of hops) and the level of packet loss along the path. The ETX metric is defined as the expected/required number of transmissions/retransmissions in the network layer that is necessary for packets to be successfully transmitted by a wireless link. The ETX metric is calculated consecutively in each intermediate node separately for each link that belongs to the path (Fig. 6). The path metric is calculated as a sum of all ETX metrics determined in successive nodes of the network. The basic disadvantage of the metric is the application of data packets for the calculation of data packets that are of small size, which is followed by the fact that thus obtained results may not be representative for a real traffic. Another disadvantage includes the assumption, adopted in calculations, of the

symmetry of traffic. In addition, the ETX metric does not take into account potential radio interference between individual nodes of the network and the existence of nodes with a number of radio interfaces in the network.

Expected Transmission Time (ETT) The Expected Transmission Time (ETT) metric has been developed from the ETX metric and, regrettably, has all the shortcomings of the latter. The ETT metric is proposed in [7]. Its advantages include the inclusion of the influence of the changes in bit rate, that occur between individual nodes in the determined path, on the value of the metric. ETT is determined on the basis of the following dependence:

$$ETT = ETX \times \frac{PacketSize}{Bandwidth}. \quad (1)$$

As it results from Eq. (1), the metric value is influenced by both available band and also the size of a transmitted packet (Fig. 7). This is still not good enough and the ETT metric does not fare well in networks in which nodes have more than one radio interface. Other disadvantages of ETT include the lack of inclusion of radio interference, both inter-flow and intra-flow, as well as the load of the link. The undoubted advantages of ETT include the inclusion of the value of loss ratio and the length of the path. It should also not be forgotten that an application of this metric guarantees a choice of paths that lack loops and its calculation is relatively easy.

Other modifications to the ETX metric A typical ETX metric is determined with the assumption of the statistical nature of transmission channels. This means that effectiveness of the operation of these routing protocols that use ETX will be reduced. Because of the above shortcoming, a number of modifications of the ETX metric has been proposed. The modifications aim at eliminating this limitation as much as possible, thus they aim at making the real properties of channels better rendered. The most commonly used modifications include [10]:

- Modified ETX (mETX),
- Effective Number of Transmissions (ENT),
- Effective Number of Transmissions (ENT).

The metric **Modified ETX (mETX)** is discussed in [10]. mETX is a modification to the ETX metric that takes into consideration, besides the standard ETX parameters, changeability of link parameters in time:

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

In Formula (2) the parameters μ and σ return respectively the value of the average packet loss and the variance of packet loss ratio.

Characteristics of the link changeability in time provide an opportunity to take advantage of the mETX metric directly for the mapping of the transmission quality in the network layer and in the application layer.

The metric **Effective Number of Transmissions (ENT)** is proposed in [10]. ENT makes use of the number of successive retransmissions (for each link) taking also into account the variance of packet loss ratio:

$$ENT = \exp\left(\mu + \frac{1}{2}\delta\sigma^2\right). \quad (3)$$

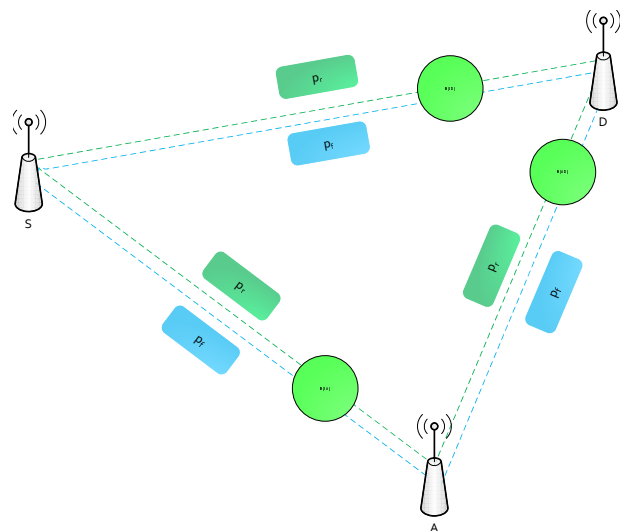


Fig. 7: Expected Transmission Time Metric

In Formula (3) the parameter δ expresses the strictness of loss rate requirements. If the value of this parameter exceeds the assumed level, then in the ENT metric the infinity value is transmitted, which disqualifies a given path in the routing process.

The ENT metric promotes (favours) links that are characterized by a defined, acceptable number of retransmissions. In their operation, the mETX and ENT metrics take into account the loss ratio and the lengths of individual paths, while they guarantee a selection of loop-free paths and get the basic ETX metric close to quality-aware metrics. The disadvantage of both metrics is the lack of possibility to take into account interference and load of particular links.

The metric **Exclusive Expected Transmission Time (EETT)** is described in [1]. EETT makes it possible to select a path in multichannel (multirate) radio network with as low amount of interference as possible. The EETT metric, as compared to the ETT metric, assumes additionally that the connection path is not homogeneous and the links between individual nodes can have different characteristics:

$$EETT_l = \sum_{l \in S(l)} ETT_l. \quad (4)$$

The path that is preferred by EETT will be such a path for which the amount of interference is as low as possible, while individual links between nodes take maximum advantage of the diversity of channels.

Weighted Cumulative Expected Transmission Time

The metric **Weighted Cumulative Expected Transmission Time (WCETT)** is proposed in [7]. WCETT is a modification of the ETT metric that takes into account diversity of channels in networks that make use of many radio channels (Multi-channel radio networks). The WCETT metric takes into account intra-flow interference and channel diversity (Fig. 8). Values of interference and diversity are appropriately multiplied by the variable parameter β

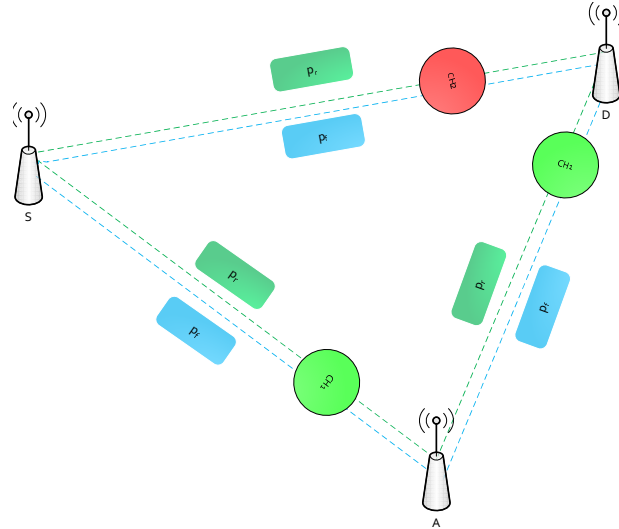


Fig. 8: WCETT Metric

that has been introduced to assign appropriate weights to them:

$$WCETT = (1-\beta) \sum_{i=1}^n ETT_i + \beta \max_{1 \leq j \leq k} X_j. \quad (5)$$

In Formula (5), X_j denotes the sum of times necessary for packet transmission by each node that makes use of the j channel. This parameter can be determined on the basis of the following dependence:

$$X_j = \sum_{i \text{ uses channel } j} ETT_i. \quad (6)$$

The WCETT metric determines the cost of a given path, while its lower values denote paths that use more diverse channels, i.e., those that are characterized by lower intra-flow interference. Unfortunately, WCETT does not take into consideration inter-flow interference and link loads. Another disadvantage of this metric is the lack of isotonicity, which does not guarantee loopless paths selections.

Metric of Interference and Channel Switching (MIC)

Metric of Interference and Channel-switching (MIC) - is proposed in [23]. MIC is a modification of the WCETT metric in which problems with inter and intra-flow inter-

ference as well as the problem of the lack of isotonicity have been solved (Fig. 9). The MIC metric is defined with the following dependence:

$$MIC(p) = \frac{1}{N \times \min(ETT)} \sum_{link\ l \in p} IRU_l + \sum_{node\ i \in p} CSC_i. \quad (7)$$

In Formula (7) the parameter N denotes the total number of nodes in the network, $\min(ETT)$ is the lowest value ETT in the network, whereas the parameters IRU (Interference-aware Resource Usage) and CSC (Channel Switching Cost) can be determined on the basis of the dependencies (8) and (9).

$$IRU_l = ETT_l \times N_l. \quad (8)$$

In Formula (8) the parameter N_l denotes a set of neighbouring nodes transmitting along the link l that are in mutual interference.

$$CSC_i = \begin{cases} w_1 \text{ if } CH(prev(i)) \neq CH(i) \\ w_2 \text{ if } CH(prev(i)) = CH(i) \end{cases} \quad 0 \leq w_1 \leq w_2 \quad (9)$$

The parameters $CH(i)$ and $prev(i)$ in Formula (9) denote respectively the channel used for transmission through node i and the previous hop for node i along path p . The IRU parameter can be interpreted as a combined occupancy time of a radio channel by adjacent (neighbouring) nodes. Therefore, the lowest value of the IRU parameter indicates a path for which the time of such an occupancy is the lowest, i.e., a path for which the intra-flow interference level is the lowest. The CSC parameter is responsible for the inter-flow interference level. CSC allows the paths that use the same radio channel to be given higher weights than paths using different channels. This means that paths on which the level of inter-flow interference is the lowest will be favoured.

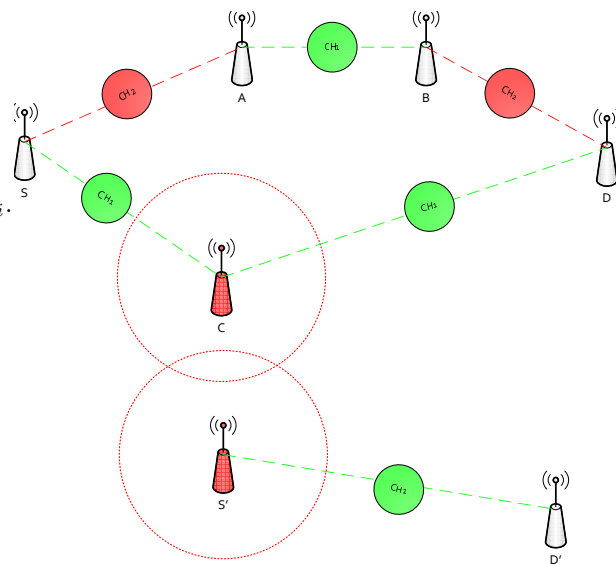


Fig. 9: Metric of Interference and Channel Switching

A disadvantage of the MIC metric is its lack of taking into account link loads and the location (placement) of nodes in a network. The operation of MIC also increases link overhead. Another disadvantage of MIC metric is the lack of the possibility to differentiate neighbouring nodes into active and idle nodes. This means that all neighbouring nodes are taken into account as potential interference sources, on condition that they use channels that can introduce interference. The MIC metric, when applied directly, is not isotonic. [23] proposes a method for a division of the network into virtual nodes that would map real nodes and such a decomposition of MIC metrics that can effect in obtaining isotonicity of the MIC metric. The unquestionable advantage of the MIC metric is its capability of reducing the influence of interference, both inter-flow and intra-flow, on the operation of the network.

Interference Aware Routing Metric (iAWARE) The iAWARE metric is proposed in [21]. iAWARE makes an attempt to improve some of the shortcomings of the MIC metric by making use of another, more accurate, interference model. In this model, the authors take advantage of

the relation between $SINR$ (Signal to Noise Plus Interference Ratio) and SNR (Signal to Noise Ratio). In this particular case, the interference level derived from neighbouring nodes is continuously translated into the value of the metric. The iAWARE metric assesses the average occupancy time of the medium caused by interference from adjacent nodes. The bigger the interference influence, the greater value of the iAWARE metric. The iAWARE metric is defined in the following way:

$$iAWARE = (1 - \alpha) \sum_{i=1}^n iAWARE_i + \alpha \max_{1 \leq j \leq k} X_j. \quad (10)$$

In Formula (10) the parameter X_j denotes the value exactly as it is in the case of the WCETT metric, k is the combined number of channels, n is the number of links, whereas p indicates the network's path. The variable parameter α is chosen depending on the environment and defines the relation between the intra-flow interference and inter-flow interference. The iAWARE metric can be determined on the basis of the following formula:

$$iAWARE_i = \frac{ETT_i}{IR_i}, \quad (11)$$

where the parameter IR_i corresponds to the interference level in the link according to the following dependence:

$$IR_i = \frac{SINR_i}{SNR_i}. \quad (12)$$

In general, as it is in the case of the MIC metric, iAWARE is not an isotonic metric. A disadvantage of this metric is the lack of a possibility to detect interference on the part of the sender, and the lack of measurements of the interference level in the MAC layer. The metric does not support network load equalization mechanisms, either.

Interference Load Aware Routing Metric (ILA) The Interference Load Aware Routing Metric (ILA) is an example of a hybrid metric. LLA takes into account both loads of paths and the bandwidth, as well as interference between nodes. The LLA metric is defined exactly as the

MIC metric, with the only difference in that, instead of the number of nodes that interfere with one another, the amount of data transferred between nodes is taken into consideration. A definition of the metric is expressed by the following dependence:

$$ILA_p = \alpha \times \sum_{link \ i \in p} MTI_i + \sum_{node \ i \in p} CSC_i, \quad (13)$$

where p denotes path MTI - Metric of Traffic Interference, while CSC - Channel Switching Cost. The parameter MTI determines the amount of traffic generated by interfering nodes:

$$MTI_i(C) = \begin{cases} lETT_{i,j}(C) \times AIL_{i,j}(C) & \text{if } N_i \neq 0 \\ ETT_{i,j}(C) & \text{if } N_i = 0. \end{cases} \quad (14)$$

In Formula (14) the parameter ETT is a component that distinguishes the difference between transmission rates and packet loss ratios, whereas the parameter AIL (Average Interfering Load) for nodes i and j that use channel C for transmission is defined as follows:

$$AIL_i(C) = \frac{\sum_{N_i} IL_{ij}(C)}{N_i(C)}, \quad (15)$$

where $N_i(C)$ denotes a set of nodes that interfere with one another, and the parameter IL_{ij} is the link load between these nodes.

The parameter CSC is defined in exactly the same way as the parameter with the same name in the dependence (9), while the constant α is used to control the scale of the metric and its value depends on the influence of the parameters MTI and CSC on the end value of the metric.

A disadvantage of the LLA metric is that it induces a considerable increase in traffic in the network. Being a metric that is based on ETT and ETX, it inherits all of the shortcomings of its predecessors. The metric neither takes into account delays in transmission in links nor the location of nodes in the network.

Interferer Neighbors Count Routing Metric (INX)

INX is a modification of the ETX metric. The INX metric introduces an additional parameter that is responsible for interference. The value of the INX metric is calculated on the basis of the following dependence:

$$INX_j = ETX_j \cdot \sum_{k \in N_j} r_k. \quad (16)$$

In Formula (16) the parameter N_j denotes the number of interfering nodes as a result of a transmission along the link j , whereas r_k is transmission rate for the link k .

The INX metric is isotonic and takes into account asymmetry of links, thus being more effective than the MIC metric. A disadvantage of the INX metric is its lack of load equalization mechanisms, which in consequence limits its application to networks in which network load is not significant.

3.2.3 Energy-aware Metrics

Minimal Total Power routing (MTPR) One of the first Minimal Total Power routing (MTPR) metrics is proposed in [19]. The MTPR metric aims at minimizing the total energy consumption. The authors of [19] define the energy necessary for a successful transmission of one packet from node i to node j as $e_{i,j}$. Hence, the total energy necessary for a successful transmission of a packet through a path p that is composed of nodes n_1, \dots, n_k is:

$$E = \sum_{i=1}^{k-1} e_{n_i, n_{i+1}}. \quad (17)$$

On the basis of Formula (17) it is possible to make a choice of a path for which the energy consumption necessary for a transmission of the packet is the lowest. In the case of scenarios in which the load of links will be low, the MTPR metric will be operating exactly as the Hop-count metric, whereas in the case of loaded links for which the energy expense necessary for the packet transmission will be much higher (e.g. due to the retransmission process), the MTPR metric will operate in a similar way to the op-

eration of the ETX metric.

A disadvantage of this metric is the lack of the inclusion of the real energy level in batteries in nodes, which can cause the nodes that are more promoted to consume more energy to a significantly larger extent.

Minimal battery cost routing (MBCR) The Minimal Battery Cost Routing (MBCR) metric is presented in [4]. MNCR takes into account the remaining level of battery load in a node. This level is defined as follows (18):

$$R_{brc} = \frac{E_i}{E_{max}} = \frac{\text{Battery remaining capacity}}{\text{Battery full capacity}}. \quad (18)$$

A disadvantage of this metric is the averaging of the value of the remaining energy for the whole path, which means that only those paths that include nodes with a very low energy level can be promoted (Fig. 10). In order to solve this problem, a number of ways of categorization of nodes on the basis of their energy level have been proposed to include only those nodes that satisfy the minimum criteria in terms of the remaining energy. There are also some modifications to the MBCR metric, i.e. Min-Max Battery Cost Routing (MMBCR) and Conditional max-min battery capacity routing (CMMBCR).

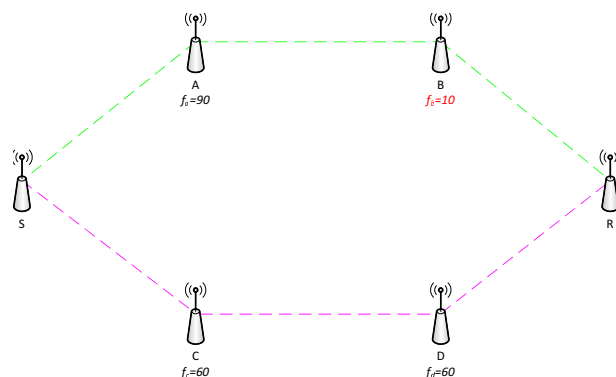


Fig. 10: Minimal Battery Cost Routing Metric

3.2.4 Signal Strength Based Metrics

Successful packet delivery in case of signal strength is in some range allows to treat signal strength as an indicator

for quality of link. There are two different ways of using signal strength as a metric: (i) As a control parameter; paths with quality below expectations are not taken into account in the route selection process (ii) As conventional routing metric; signal strength considered in route or link cost function. Actually there are some metrics proposed by researchers as Preemptive Routing [9], SSAR [8] or Link quality factor [17], but popularity of use of them is rather marginal.

3.2.5 Mobility-aware Metrics

Active probing metrics are not well suitable in mobile scenarios; frequent changes of routing paths can make network unstable, measurement based metrics need time to be calculated. In mobile scenarios Hop-count metrics perform better; new links can be used as soon as they appear. Mobility-aware metrics are choosing paths with higher expected lifetime to minimize routing overhead and changes of route. These metrics often use signal strength as a criterion for the evaluation of the link stability. The most commonly used metrics of this type include: Link Affinity Metric [22], ABR (Associativity-based routing) [16] czy RABR (Route-Lifetime Assessment Based Routing) [2]. As in the case of the metrics based on signal strength, mobility-aware metrics are not particularly popular and are used in particular applications only.

4 Conclusions

The article presents an overview and comparison of metrics used in routing protocols in WMN networks. Tab. 1 presents comparison of metrics and includes such parameters as bandwidth, loss ratio and interference.

Metrics have been divided into five categories according to their features: Hop Count Metrics, Active-probing Metrics, Energy-aware Metrics and Signal strength Metrics. The authors' intention is to provide a description of existing metrics. The conducted analysis will form a

starting point for further works aimed at proposing appropriate modifications to routing protocols metrics in WMN networks.

While analysing the presented metrics it can be noticed that there is no single routing metric that would fit all possible purposes and applications in the WMN network, while a choice of a given metric and a particular routing protocol mostly depends on the application of a given network.

The presented comparison also shows a particular popularity of the hop-count metric. The popularity of this metric mainly results from its simplicity that often remains a choice decisive factor.

A further stage of work will involve simulation experiments that will be aimed at examining the relations between routing metrics and the effectiveness of selected routing protocols used in WMN.

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Tab. 1: Comparison of the most representative routing metrics

Name	Type	Layer	Bandwidth	Loss Ratio	Load Aware	Inter-flow interferences	Intra-flow Interferences	Isotonic
Hop Count	Simple	Network						✓
Blocking Metric	Simple	Network				✓		✓
RTT	Active Probing	Network	✓		✓			✓
PktPair	Active Probing	Network	✓		✓			✓
ETX	Active Probing	Network	✓					✓
ETT	Active Probing	Network	✓	✓				✓
MTM	Active Probing	Network	✓	✓				✓
mETX	Active Probing	Network	✓					✓
ENT	Active Probing	Network	✓					✓
WCETT	Active Probing	Network	✓	✓				✓
MIC	Active Probing	Network	✓	✓		✓	✓	✓
INX	Interference-Aware	Link	✓	✓		✓	✓	✓
iAWARE	Interference-Aware	Link	✓	✓		✓	✓	
ILA	Load and Interference -Aware	Network, Link	✓	✓	✓	✓	✓	✓

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