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OPTIMIZATION OF LOAD BALANCE LINK LAYER PROTOCOL FOR NODES WITH MULTIPLE CHANNELS AND INTERFACES IN WIRELESS MESH NETWORKS: A COMPREHENSIVE REVIEW

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ABSTRACT
Wireless mesh network (WMN) is the most efficient wireless technology not only due to its numerous applications but also have low cost, easy network maintenance, robustness and reliable service coverage when compared with the existing wireless networks such as Ad-hoc, VANET, sensor networks. Despite these benefits the major challenge with WMN is to balance the traffic load through cooperative channel allocations for nodes with multiple channels and interfaces. However, the Load Balance Link Layer Protocol (LBLP) balance the traffic load according to the dynamic traffic with uniform or non-uniform traffic patterns and it performed well with LAR routing metric. But other existing metrics such as ETT, WCETT, iAware need to be modified to be compatible with the protocol. This work provides a thorough review of the current state-of-the-art routing techniques used in WMN and cooperative allocation research. The techniques reviewed are suitably classified into optimization goals, computational techniques, and routing metric functions, where the techniques at each stage are studied and their merits are compared. Moreover, we discuss the challenges and shortfalls faced by cooperative allocation, as well as those exclusive to LBLP. Thus, propose three modified metrics; LPER, LPWR and LPiAR to work well with LBLP protocol. It is hoped that the study may provide readers with introduction into the node equipped with MC-MI WMN and further facilitate future research efforts in the area.
keywords— Wireless mesh network, Load balance link layer protocol, Routing metrics, multiple channels multiple interfaces, Interference.

INTRODUCTION

Proliferation of the mobile world has rendered the typical ways of networking the globe ineffective to meet the users demands. Thus, created an avenue to encroaching wireless technologies. But, IEEE 802.11 (member of the IEEE 802 family) is the most successful wireless technology so far (Gast, 2002). Despite significant progress in IEEE 802 family, wireless mesh network (WMN) is the most efficient wireless technology due to its adaptation in educational field, neighborhood networks, enterprise networks, disaster management, broadband home networking, building automation networks etc. with number of advantages (Zehni, Zolfaghari, & Fathy, 2017: Karthika, 2016: Ullah, Kiani, Ali, & Rizwan, 2016). A general WMN as shown in fig.1 is a multi-hop wireless network which comprises of connected wireless devices, such as mesh routers which relay packets through wireless channels, mesh gateways are also connected with high speed wired network to the internet (Kandah, Zhang, Wang, & Li, 2012) and mesh clients are client nodes and provide the end-user applications to subscribers of the mesh networks. They include mobile phones, laptops and other wireless devices (AbdelHamid, Hassanein, & Takahara, 2013).

The following are the characteristics of WMN: dynamic self-configuration, self-organization, adaptation, Multi-hop wireless network, fault tolerance, robustness, capability of self-forming, self-healing, mobility dependence, multiple types of network access, interoperability etc. It has the following key design factors: scalability, ease of use, compatibility, interoperability, mesh connectivity (Zehni et al., 2017). However, these advantages cannot be fully realized, if issues such as node deployment, channel diversity, switching overhead, and interference are not properly handled. Consequently, the network suffers from having non-standard internet protocol.

However, the need for more efficient and low-cost hardware urge nowadays network nodes to use multiple channel and multiple interfaces.

Compared to the conventional network nodes, there are significant differences, with respect to routing protocol in the IEEE 802.11a, b/g standards, and the conventional routing metrics. The conventional routing protocols like AODV and DSR for multi-radio networks cherry-picked shortest-path routes, it is hard to be used for multi-channel networks. Previously conducted research suggests that the cooperative channel assignment and link schedules are the critical factors for MC-MI wireless mesh networks (Wang, Shi, Xu, & Li, 2019 : Zehni et al., 2017). Considering that cooperative networks are complex WMNs, the inherent differences with the conventional WMN is the diverse channel throughput of a route, interferences along the route, and adaptive local and gateway traffic. Nevertheless, to accurately capture these three properties, there is need for good routing metrics. LBLP introduced in (Deng et al., 2019), balance the traffic load by adapting interfaces in both the local and gateway traffic, with outstanding performance but the minimum cost paths, bandwidth adjusted conventional routing metrics such as ETT, WCETT and iAware cannot work with the protocol.

To make modifications to the conventional metrics, there are already drawn increased attention by the researchers. Some publications provided overviews of the design of good routing metrics in multiple interfaces (SilvaMineiro, & Muchaluat-Saade, 2014: Karthika, 2016), while others emphasized more specific aspects, where channel diverse route, and self-interference along the route were incorporated on the new proposed metric (Pradeep and Nitin, 2007: Raniwala, Gopalan and Chiueh, 2012). The work in (Draves, Padhye, & Zill, 2004), assumed equal number of interfaces and channels used by the network, this metric cannot be employed on the general case.

However, significantly fewer researches on cooperative channel allocation and scheduling focused different ways in which relays can be deployed to improve performance, but the works mainly concerned with energy efficient, and wireless channel diversity (Chai, Shi, Shi, & Yang, 2017: Porkodi, Khan, Salih, Bhuvana & Sivaram, 2019). In (Kun, Shiming, Xin, Dafang & Keqin, 2017) proposes two metrics that effectively considers interference cost from direct and cooperative transmission, and channel load condition. The metrics have unbounded performance increase as the number of channels increase further. Besides, cooperative methods that employed the OLSR routing protocol (SilvaMineiro, & Muchaluat-Saade, 2014 : Porkodi, Khan, Salih, Bhuvana & Sivaram, 2019) will get the data packets drops, due to the participation of all the nodes in the routing which might have cause disturbance. Traffic loads can be categorized into different traffic-related factor values to find routes for flows, but suffer interference issues (Wang, Shi, Xu, & Li, 2019). All these work mentioned above have demonstrated that the effective routing metric and uniform traffic load are helpful for improving performance of cooperative channel allocation and scheduling. The works reflects the state-of-the-art as well as potential future direction is missing. This paper aim to fill this gap by providing a comprehensive state-of-the-art studies in cooperative routing metrics problems with relevant classifications.

Therefore, it is very difficult to deploy existing routing metrics for nodes with MC-MI in LBLP through cooperative channel allocation and scheduling. Inspired by discussions above, and the work in (Deng et al., 2019), to attach these challenges, routing metrics is investigated based on a) optimization goals, b) way of acquiring information to calculate the metric and c) the function employed to calculate the metric, on previous, recent, and ongoing researches. Limitations are identified, possible recommendations are given.

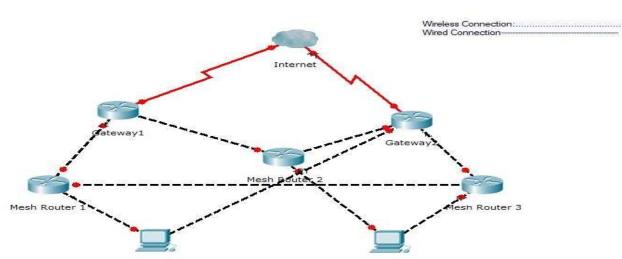

Figure 1. General Architecture of Wireless Mesh Network.

MATERIALS AND METHODS

This paper study only routing of nodes with MC-MI for WMN. Concisely, accounts for three configuring points; a) optimization goals, b) way of acquiring information to calculate the metric and c) the function employed to calculate the metric. The points be exhaustively visited from past, current, and ongoing research, as they affect the routing performance. It is evident that the metric computation requires any one or all of the following information at nodes (Parissidis et al., 2009): a) Local information b) passive monitoring. c) active probing. d) Piggyback probing. In addition, it is crucial to consider metric filtering: fixed history interval, dynamic history window, and exponentially weighting moving average (EWMA). Taxonomy is developed based on the parameters in (J. Li, Silva, Diyan, Cao, & Han, 2018), to explores individual limitations that rendered existing metrics inconsistent See Table 1. We would propose modifications to three existing routing (LPER, LPWR and LPiAR) metrics based on LBLP protocol and simulated via NS3-19, if design would achieve an adaptive dynamic load balancing, optimal channel utilization and least routing overhead. This work would adopt IEEE 802.11a and evaluated based on throughput, load balance and interference level, respectively. And the performance results would be compared with the current state-of-the-art.

RESULTS/EXHAUSTIVE FINDINGS

Routing in WMN: Exhaustive Findings

There exists number of routing protocols and packet forwarding mechanisms in current WMNs. Three routing protocols are identified as key in WMNs (Jun Wang, Li, Jia, Huang, & Li, 2008: Karthika, 2016: Si, Selvakennedy, & Zomaya, 2010: Ding & Xiao, 2011: Mo et al., 2018). Effective routing algorithms can mitigate potential congestion on any gateways to the internet, thereby improving per-client throughput (Manshaei & Hubaux, 2007), hence routing is one of the major challenges in meshing. Thus, these protocols are not applicable to LBLP, due to individual limitations as explored in (Karthika, 2016). Therefore, multipath routing can be another option for meshing, not only it facilitate load balancing, also improves transmission reliability and quality of service (Chakraborty & Debbarma, 2017: Mo et al., 2018: Wei-wei et al., 2017). Considering the aforementioned issues have been proven critical due to factors such as time varying channels, variable packet loss, packet transmission rate, and interference (Subramanian, Buddhikot, & Miller, 2006). Routing metrics is the solution to trade-off these factors. The following are widely used routing metrics: a) Expected transmission count (ETX), Table 1 refers, (Al-saadi et al., 2016). The expected number of transmissions required to successfully deliver a packet from point A to B after n attempts is denoted with $q(n)$, if the probability p for the packet transmission is not successful, then the ETX is (Draves, Padhye, & Zill, 2004):

$$ETX = \sum_{n=1}^{\infty} n \times q(n) = \frac{1}{1-p} \quad (1)$$

In b) Expected Transmission Time (ETT), improved ETX, table 1 refers (Subramanian, Buddhikot, & Miller, 2006 : Al-saadi et al., 2016):

$$ETT = ETX\frac{P}{B} \quad (2)$$

c) Weighted Cumulative Expected Transmission Time (WCETT), assumed all the links along path n have ETT_i as the sum of all ETT_s, with X_j as the summation of all ETTs on the most consumed channel, j, c is the number of orthogonal channels available on the network, β is a tunable parameter that assigns weights to path length and channel diversity (Parissidis, Karaliopoulos, Baumann, Spyropoulos, & Plattner, 2009):

$$WCETT_n = (1-\beta)\sum_{i\epsilon n} ETT_i + \beta.\max_{1\le j\le c} X_j \quad (3)$$

d) Interference Aware (iAware) routing metric; solved the individual limitations of the existing metrics (Ullah et al., 2016). It is obtained from:

$$iAware_n = (1-\alpha)\sum_{j=1}^{n} iAware_i + \alpha.\max_{1\le j\le c} X_j \quad (4)$$

For all the links along path n have $iAware_i$ as the sum of all $iAware_s$, with X_j as the summation of all $iAware_s$ on the most consumed channel, j, c is the number of orthogonal channels available on the network, α is a tunable parameter that assigns weights to path length and channel diversity, thus it has static value throughout the network operation, therefore the iAware metric of path n along link j is obtained as in (5), (Ullah, Kiani, Ali, & Rizwan, 2016):

$$iAware_j = \frac{ETT_j}{IR_j} \quad (5)$$

The interference ratio is defined in (6), also interference ratio for a node u along link $j = (u), (v)$ where $(0 < IR_j \le 1)$:

$$IR_j = min[IR_j(u).IR_j(v)] \quad (6)$$

$$IR_j(u) = \frac{SINR_j(u)}{SNR_j(u)} \quad (7)$$

e) The Weighted Cumulative Consecutive ETT (WCCETT), modified WCETT for accurate estimation of intra-flow interference (8). New term calculated only consecutive channels, and Y_j is the sum of all ETT_s of links that are on segment j (Paul, Majumder, & Roy, 2012).

f) Weighted Cumulative Conflicting ETT (WCConfETT), conflicting hop is introduced in (Paul et al., 2012), to make the metric very sensitive to intra-flow interference. It selects a path with minimum end-to-end delay (Saleem, Salim, & Husain, 2014).

$$WCCETT_n = (1-\beta)\sum_{i\epsilon n} ETT_i + \beta.\max_{1\le j\le c} Y_j \quad (8)$$

$$Y_j = \sum_{Hop\ i\ on\ segment\ j} ETT_i\,, \quad 1 \le j \le c \ (9)$$

$$WCConfETT_n = (1-\beta)\sum_{i\epsilon n} ETT_i + \beta.\max_{1\le j\le c} Z_j \ (10)$$

$$Z_j = \sum_{Conflicting\ hop\ i\ on\ channel\ j} ETT_i\,, \quad 1 \le j \le c \ \ (11)$$

However, ETT fails to explicitly estimate the logical interference, while WCETT is non-isotonic metric, has static view of channel, unable to estimate the least cost path, and fails to explicitly estimate the logical interference. The iAware metric is non-isotonic, has static view of channels, and cannot estimate the logical interference accurate. It is evident that the three proposed existing metrics cannot be adopted on cooperative channel allocation and scheduling in LBLP due to their individual limitations. However, modification/integration to these individual metrics is very essential to find efficient path and to balance the traffic load. The following are summarized as key design issues in routing metrics: latency/throughput, distance, error rate, composition, traffic load, multi-channel, and channel usage (Zehni et al., 2017). In addition, characteristics of mesh routing must be assured (Gore & Karandikar, 2011): intra-flow interference, inter-flow interference, logical interference, external interference, information from local node, agility, stability and throughput. Also, the following elements are crucial to exploit while selecting a routing metrics: number of hops, link capacity, link quality and channel diversity.

The notations of Table 1: presents a grading system of general routing metrics, with A correspond to strong consideration of the design factor, while B correspond to show consideration, C correspond not consider.

Table 1: Comparison of General Existing Routing Metrics for Nodes with MC-MI in WMN.

Routing Metrics	Path length	Loss Ratio	Link Capacity	Intr-Interference	Int-Interference	Load Balancing
ETX	A	B	C	C	C	C
ETT	A	A	A	C	C	C
WCETT	B	A	A	B	C	C
WCCETT	B	A	A	A	C	C
WCConfETT	A	A	A	A	C	C

Table 2: Routing Metric Taxonomy for Nodes with MC-MI in WMN

Metrics	Goals	Computational Techniques	Routing Metric Function
WCETT-LB (Ma & Denko, 2007)	- Balance the Traffic load - Minimized queuing delay	Local Information	Summation
LAETT (Aiache, Conan, Lebrun, & Rousseau, 2008)	- Ease bandwidth requirement for the flow - Balance the traffic load	Active Probing	Multiplicative
LARM (Le, Kum, & Cho, 2008)	- Balance Traffic load - Minimized Interference	Local Information	Summation
ILA (Shila & Anjali, 2008)	- Minimized Interference - Minimized packet loss	- Passive measurement - CSC	Summation

Table 2 continue

	ratio - Control congestion		
ETT-LB (S. Yang, Lee, Yun, Han, & Yun, 2009)	- Balance traffic load - Utilized link	- Active probing	Summation
WConfCETT (Paul et al., 2012)	Minimized intra-flow interference	Local information	Summation
EPT (Deng et al., 2015)	- Balance network load - Maximize throughput - Minimized delay - Minimized interference	- Local information - Global information - Active probing	- Summation - Algorithm decision
ELARM (Kiani et al., 2015)	- Minimized residual energy consumption - Minimized link congestion	- Local information - Energy level info.	Summation
ILC (Sharma, Kumar, & Singh, 2015)	- Maximized throughput - Minimized delay - Minimized residual energy of the nodes - Maximized expected rate of lifetime	- Active probing - Local information	Routing algorithm decision
LBR (X. Wang & Tan, 2015)	- Balance traffic load - Minimized interference - Maximized throughput	- Local Information - Network model	Algorithm decision
NAIA (Ullah et al., 2016)	- Maximize probability of data delivery - Minimized interference - Minimized delay	Local information	- Summation - Algorithm decision
CRS (Xie et al., 2016)	- Minimized delay - Maximized capacity reduction in overload	Local information	- Summation - Algorithm decision
SPR (J. Xu, Guo, & Yang, 2016)	- Maximized probability of data delivery - Minimized delay - Minimized interference	Local information	Summation
CHRP (Chai, Shi, Shi, & Yang, 2017)	- Minimized interference	- Local information	- Summation - Algorithm

Table 2 continue

	- Balance load - Minimized residual energy consumption	- Passive monitoring	decision
REMA (Shi, Chai, & Liu, 2017)	- Minimized residual energy consumption - Extend network lifetime - Improve route stability	MREMA Passive monitoring	Summation
xWCETT (Kola & Velempini, 2018)	- Minimized packet delivery - Probability of channel availability	Local information Global information	- Summation - Algorithm decision
CL-IDA (Narayan & Mudenagudi, 2018)	- Minimized Interference (intra&inter) - Estimate Delay	- Analytical model - Piggyback probing	- Algorithm decision
CBRM (J. Li et al., 2018)	- Reduced flooding overhead - Reduced path search time - Minimized delay	Active probing	- Summation - Algorithm
NSR (Boushaba, Hafid, & Gendreau, 2017)	- probability of selecting gateway - consider stability index	Entropy	Algorithm decision
RCA-HRP (Chai & Zeng, 2019)	- balance traffic load	Global information (mesh routers and mesh clients)	- Summation - Algorithm decision
LBLP (Deng et al., 2019a)	- minimized queuing delay - balance load - minimized interference	Local available information	Algorithm decision
AODV routing (Yang, Li, Wang, & Xiao, 2019)	- minimized interference - balanced load	Local information	Algorithm decision
FLRA_discrete (Wang, Yao, Zhang & Li, 2019)	- flow-level cross-layer resource allocation - balanced load	Global information	Lagrange Multiplier.

This paper proposes LBLP with ETT (LPER), LBLP with WCETT (LPWR) and LBLP with iAware (LPiAR) routing metrics, respectively, due to the short falls of routing metrics in section 3.1. the modifications are proposing as follows: term is introduced to accurately estimate link delivery, control term would be adjusted to estimate logical interference, and metrics will be made adaptive to probe airy exchange. The proposed new routing metrics will ensure load balancing, scalability, maximum throughput, minimum interference among other factors.

Performance Quantification for Nodes with MC-MI in LBLP: The performance of our proposed routing metrics would be evaluated via NS3-19 simulation. The parameters to be used in the simulations are network throughput, interference, and load-balancing index

According to (Manshaei & Hubaux, 2007), throughput is given by:

$$T_j = f(c_j, n_j) \quad (12)$$

The total throughput of the network is:

$$T_t = \sum_{j \in link\ set} T_j = \sum_{j \in link\ set} f(c_j, n_j) \quad (13)$$

The load-balancing index LB_i would be used to quantify the network traffic balance. With $f(e)$ as the total flow of link e, P as set of links which incorporates all flows, N as number of links in P, while f represents average load of links in P. LB_i is given in (X. Wang & Tan, 2015):

$$LB_i = \sum_{l \in P} \frac{f(e) - \bar{f}}{N\bar{f}} \quad (14)$$

The smaller the value of LB_i the better the traffic load balance of a given network. These analysis would be performed for each link in the network connectivity graph, and the algebraic sum is the theoretical results of the total throughput of the network (G. Li, Hu, Peng, Zhou, & Xu, 2018).

CONCLUSION AND FUTURE DIRECTIONS

LBLP through cooperative channel allocation and scheduling techniques have an exceptional and attracting strengths over the conventional approach where only one fixed channel is used for local traffic, which is undesirable at high local traffic volume, which have become an active research direction in recent. LBLP architecture has been successfully established by combining the modified AOD with LBLP (LAR) which has proven to be accurate even when the switching delay is large, and it gives a uniform load distribution. This paper systematically reviews existing routing metrics for cooperative channel allocation and scheduling in mesh networks. The surveys in Table 1 and 2 provides the classification, based on the major cooperative routing metrics components: load balance, interference, and throughput. The factors, which restrict the adoption of the existing metrics on present protocol were presented and discussed. In addition, current developments, and shortcomings as well as several variants are proposed towards existing methods and modifications on the existing metrics were suggested. The first term introduced, estimate both the local and gateway traffic. This would improve the accuracy and processing time. The second modification term capture both interferences adaptively as the network shoots. The third modification term will estimate the anticipated capability of a path regarding the per-node fairness by adjusting equation 13. This review represents a concise overview of the latest developments and trends for MC-MI cooperative routing metrics, which may help inform and guide both experienced and new researchers in this developing field. There are several valuable future research directions, such as modifications of routing metrics at cross-layer design, route oscillations, and security of routing based on cooperative channel allocation and scheduling.

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