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AN EXPOSITION OF VARIOUS PARAMETERS TO ESTIMATE INTERFERENCE LEVEL IN WIRELESS MESH NETWORKS.

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ABSTRACT

The performance of wireless networks is highly dependent on the amount of interference experienced by the wireless links. Wireless networks suffer much from interference due to simultaneous traffic flows due to the shared nature of the wireless medium. This worse feature of wireless networks necessitates the prudent modeling Of interference to be used in several design areas like channel assignment, routing etc. Wireless mesh networks are a type of adhoc networks with a static backhaul network.This paper provides a comprehensive analysis of different parameters that could possibly contribute to model interference and use the same in the design of interference aware routing metric.
Keywords: *I*nter flow interference, *I*ntra flow interference, *L*ogical interference, *P*hysical interference, *s*elf interference,*W*ireless mesh networks.

1. INTRODUCTION

Several factors in wireless networks contribute to interference.The absence of dedicated bandwidth of wireless links and the shared medium contributes much to interference and hence the performance of wireless networks is degraded to a greater extent.Transmissions from neighbouring nodes may compete for the same bandwidth and hence interfering with the transmissions of neighbouring links.Understanding and managing interference is essential to the performance of wireless networks. Wireless interference has to be paid a high attention as it can directly benefit channel assignment, transmit power control, routing , transport protocols, and network diagnosis. If the wireless networks becomes large in size then their performance is predominantly affected by interference.

Increasing channel diversity can reduce interference to some extent.The term channel diversity refers to the process of selecting non overlapping channels for adjacent hops of a path for a given flow. Channel Diversity can reduce interference in multi channel mesh networks but the interference reduction in single channel mesh networks is complicated and challenging.

Radio resource utilization is also enhanced by prudently managing the interference effect among the neighbouring links. Hence it is essential to analyze the various parameters like the number of packets in the output buffer of a node, received signal strength of simultaneous transmissions etc. that could be a potential source for interference so as to aid in various areas such as routing, network diagnosis etc. This paper provides an insight to such parameters.

One must be familiar with three terminologies namely transmission range, carrier sensing range and interference range to better understand the concept of interference. These are described below.

Transmission Range - The transmission range is defined as a certain radius around the sender within which transmission is possible, i.e., a receiver receives the signals with an error rate low enough to be able to communicate and can also act as sender.

Carrier Sensing Range- The Carrier Sensing Range is the range within which detection of the transmission is possible, i.e., the transmitted power is large enough to differ from background noise. However, the error rate is too high to establish communication.

Interference Range: The interference range is defined as the range within which nodes in receiving mode will be disturbed by an unrelated transmitter and hence suffers a loss.

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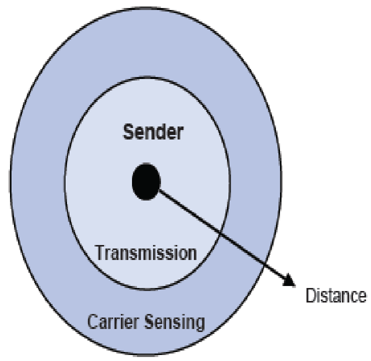

Fig:1 The General Relationship Between The Transmission Range And The Carrier Sensing Range And Their Definitions.

Section II presents a brief introduction to wireless mesh networks. Section III presents the different types of interference in wireless multi hop networks. Section IV presents the different ways of capturing interference in wireless multi hop networks as proposed by authors in their design of interference aware routing metric.

2. WIRELESS MESH NETWORKS

Wireless mesh networks are a promising technology to offer broadband wireless access to the Internet and highly preferred in places where wired infrastructure is not available or building an infrastructure is not worthy.

The Wireless Mesh Networks finds applications in a wide range of areas e.g., broadband home networking, community and neighbourhood networks, enterprise networking, building automation etc. With their inherent features of self-organization and self-configuration Wireless mesh nodes can be deployed incrementally, one node at a time, as needed.

2.1 Architecture of Wireless Mesh Networks

The architectural components of wireless mesh networks includes two types of nodes namely wireless mesh routers and wireless mesh clients. Wireless mesh routers are minimally mobile and they form the backhaul for mesh connectivity to clients. The mesh router is also responsible for forwarding the traffic to other routers and hence wireless mesh networks obey the concept of multi hop communication. This feature enables power saving. The wireless mesh routers also act as Gateways to provide Internet connectivity.[17]

2.2 Categories of Wireless Mesh Networks

Wireless mesh networks can be categorized as Infrastructure Based networks,Adhoc wireless mesh networks,Hybrid wireless Mesh networks,Single radio wireless esh networks,Dual Radio Wireless mesh networks,MultiRadio Wireless mesh networks.[17]

Backbone or infrastructure mesh networks are those in which the mesh routers are static and hence form an infrastructure of wirelessly connected routers to serve the users.The routers have multiple radio interfaces for wireless backhaul and one radio interface for connection with end users.

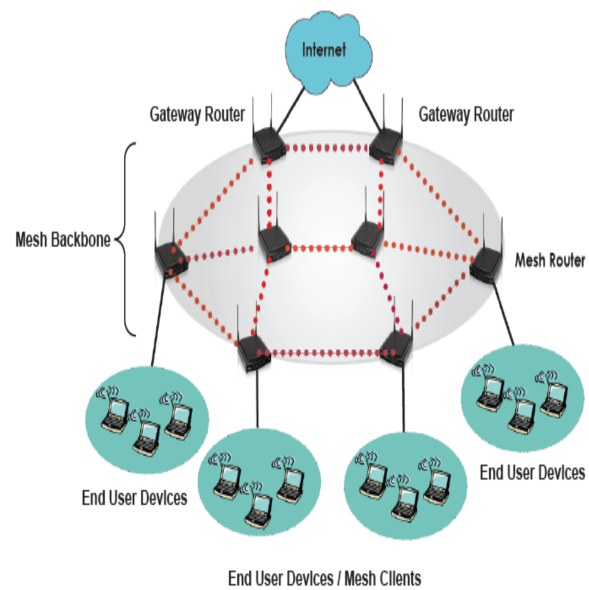

Fig:2 Wireless Mesh Networks

Adhoc mesh networks consists of a network of end user devices which self organizes to perform routing among themselves. They may be optionally connected to the wireless backhaul routers. Hybrid mesh networks combines the architectural features of both infrastructure and client mesh networks. Mesh clients can access the network through mesh routers as well as directly meshing with other mesh clients.

Single radio wireless mesh networks are the basic wireless mesh network wherein each node has a single radio and all are tuned to the same frequency. It has severe performance limitations due to the channel access procedure of several nodes contending for the same channel and hence causing much interference. And also the same

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channel is used for client access as well as backhaul access.

Dual Radio wireless mesh networks have different radios for client access and backhaul. The routers have two radios operating in two different frequencies. Hence the amount of interference experienced is lesser than single radio mesh networks. But the use of single frequency for backhaul again causes interference among routers in backhaul.

Multi Radio wireless mesh networks have the same features of dual radio mesh networks with different frequencies for client access and backhaul access. It provides more advantage because the backhaul nodes have multiple radios and hence interference among backhaul routers is considerably reduced.

3. DIFFERENT TYPES OF INTERFERENCE IN WIRELESS MESH NETWORKS

The interference in wireless links may be categorized as Uncontrolled interference and Controlled interference. Wireless mesh networks operate in the unlicensed 2.4GHz ISM band. Entities that are external to the network and using the same frequency band causes interference to data flows in the network and is called as Uncontrolled interference. These are also termed as external interference. For eg microwave ovens and Bluetooth devices operating in the same ISM band can interfere with the 802.11 b/g networks.

Due to the broadcast nature of wireless links, transmission on one link of the network interferes with the transmission of neighbouring links. Such a type of interference is called controlled interference. Interference can be intra flow interference or interflow interference[4]. Nodes on the path of the same flow may compete with each other for channel bandwidth. Such a type of interference is known as intra-flow interference. Intra flow interference increases the bandwidth consumption of the flow at each of the nodes along the path and causes the throughput of the flow to degrade sharply and the delay at each hop to increase dramatically. Achieving channel diversity is an optimistic solution to alleviate intra flow interference.

Intra-flow interference Between A and B *Better route: No intra-flow interference*

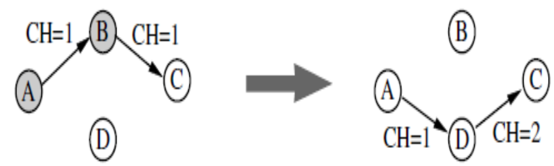

Fig:3 An Example Of Intra Flow Interference

A flow through wireless links not only consumes the bandwidth of the nodes along its path, it also contends for bandwidth with the nodes that are in the neighbouring areas of its path. Such a type of interference is called inter-flow interference. Interflow interference can result in bandwidth starvation for some nodes.

Inter-flow interference Between D and E *Better route: No-interflow interference*

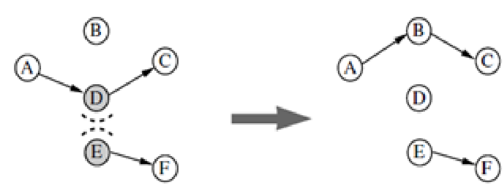

Fig:4 An Example Of Inter Flow Interference

Interference may also be categorized into two major classes based on the context of 802.11-based wireless networks. Radio Interference and Channel Contention Interference.

Radio Interference: Radio interference represents a physical interference that can influence electromagnetic waves. It represents a superposition of signal/waves which changes the original signal particularly, the amplitude of the signal is affected. It causes bit alterations which in turn cause data and/or Frame Check Sequence alteration. This alteration results in dropping of the

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packets by the link layer and hence transmission failure occurs.

Channel Contention Interference: Channel contention interference originates from the medium access procedure of wireless networks. In wireless networks the station has to wait until the channel is free to start its transmission. Channel Contention Interference primarily refers to the deferred access to medium caused by the CSMA-CA protocol because other nodes might have gained access to the channel for their transmission. Channel Contention Interference has been referred to as Interference at the MAC layer [14] and Traffic Interference[18].

Hence Channel Contention Interference may be referred as "logical" interference as it is the interference which occurs before transmission. Radio Interference comes into play during the actual transmission of the packet when interfering signals may cause failed transmissions.

As the logical Interference encompasses communication taking place on the same channel within the carrier sensing range of the node mesh routers located within this region will contend to access the channel and two nodes cannot simultaneously transmit successfully in this area. The delay that nodes have to face for accessing the channel is due to the Logical Interference. Logical Interference therefore determines when the node can actually transmit on the channel i.e. it comes into play before transmission.

Radio interference which may also be referred to as physical interference comes into play only after the transmission of signals.
Another category of interference by name self interference is also realised in wireless networks which arises due to the non optimal placement of nodes in a wireless mesh.

4. INTERFERENCE PARAMETERS

A routing metric is nothing but a path weight function (ie) a path selection criterion. Designing a routing metric that selects a path that suffers much less from interference is critical in wireless networks as the wireless networks suffer much from interference as they do not have a dedicated bandwidth. In this paper let us analyze the different parameters which the authors use to capture interference in their effort to propose different interference aware routing metric.

The **Hop count** metric is a widely used metric in many of the routing protocols. Although minimum hop path is advantageous in situations where mobility is a major concern it does not account for interference and hence not considered apt for routing in wireless mesh networks in which the quality of the link is a major consideration.
In view of the demerit of HOP count metric authors in [1] proposed **Expected transmission count metric (ETX)**.ETX [1][2] addressed interference partially as it calculates the packet loss. It was proved that the packet loss rate could be attributed as a parameter to account for interflow interference. But ETX was designed only for single radio multi hop networks and could not be appreciated for multi radio multi hop networks.
Weighted cumulative expected transmission time[3](**WCETT)** was the first routing metric that was designed for multi radio WMN. It is also the first metric to account for interference. The authors suggested that performance degradation due to interference may be alleviated by selecting a more channel diverse path. This metric considered both the bandwidth of the link and the loss rate in choosing a path. However this metric addressed only intra flow interference and hence the need to address interflow interference necessitated the design of new routing metrics.
The Metric of Interference and channel switching [4] **(MIC**) metric improves WCETT by solving its non isotonicity problem and its inability to capture interflow interference. The metric consists of two components namely **Interference resource usage(IRU)** that captures interflow interference and **channel switching cost(CSC)** that captures intra flow interference. This metric addresses that if a packet moves through a link with more interfering neighbours then the possibility of capacity reduction of a link due to interference is high. The IRU component represents the aggregate channel time of the neighbouring nodes that the transmission on a particular link consumes. MIC is not isotonic by itself but can be made isotonic by introducing the concept of virtual nodes as suggested by authors in [5].
3. Another metric that addresses both inter and intra flow interference for multi radio mesh networks named **i-Aware** was proposed by authors in [6] which tracks the changes in interfering traffic far better than ETT and IRU component of MIC. The authors has also justified that this metric has achieved intra-path channel diversity in two radio mesh networks. The authors preferred infrastructure mesh networks as it has wide commercial deployment. The authors in MIC suggested that the

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interflow interference can be captured by scaling up the ETT of the links with the number of interfering neighbours. But the degree of interference caused by each neighbouring node varies and this is a crucial factor to be considered. i-Aware addresses this property and argues that the degree of interference on a link is dependent on the signal strength of the interferer's packet. In turn this signal strength also varies based on the position of the interferer with respect to the actual sender or receiver and also the path loss characteristics. A parameter called Interference ratio (IR) of a node is defined by the metric to capture interference. The interference ratio for a node 'u' of a link i=(u,v) is defined as the ratio of the signal to interference noise ratio at node 'u' to the signal to noise ratio at node 'u'. The metric i-AWARE is the ratio between the ETT of the link and the interference ratio. i-AWARE is the first method to factor in varying interference with ETT. The concept of channel diversity is also taken into consideration into the metric.

Interference Load Aware Routing metric (ILA) was proposed by authors in [7] with an aim to route the traffic through congestion free areas and balance the load amongst the network nodes. This metric was proposed in selecting paths between mesh routers as it is agreed that the clients always send data to their respective routers and plays a passive role in route selection. The traffic load of the neighbours contributes much to interference and the routers have to keep track of the traffic load on themselves and their neighbours. ILA consists of two components namely **Metric of traffic interference(MTI)** and **channel switching cost(CSC)**.MTI captures interflow interference and CSC captures intra flow interference. The average interfering load (AIL) is the ratio between the interfering load (IL) and the number of interfering neighbours between a sender 'i' and receiver 'j'.

Adaptive Load aware routing metric (ALARM) proposed by authors in [8] considers the number of packets queued per wireless interface to represent interference and noise levels. This parameter was successful in selecting paths for Hybrid wireless mesh networks in which most of the nodes are highly mobile.

Authors in [9] paid attention to design a routing metric for large scale multi radio mesh networks in which the channel assignment on a long path is to be much considered as most of the traffic traverse a long path. They named it **Exclusive Expected Transmission Time (EETT)**.The intra flow interference is more complicated in Large Scale wireless mesh networks than in small scale wireless mesh networks. Hence the channel distribution on the long paths served as a critical parameter to find a path that suffers less from interference. The authors reported that if there are more neighbouring links on the same channel with a link 'l' then that particular link has to wait for a longer time to do the transmission on that channel. EETT metric addressed both inter and intra flow interference.

An improvement of the WCETT metric was proposed by authors in [10] by defining a parameter called **Transmission infection factor**. The metric was named as **Sum of Motivated Expected Transmission Time Metric (SMETT)** in which the complex bandwidth computation needed in WCETT was eliminated. It is believed that the amount of time a node's buffer is not empty affects other nodes' transmission on that link. Hence this factor served as a parameter to estimate the channel occupancy(ie. interference level).

Metric of Interference and channel diversity[11] **(MIND)** employs a passive monitoring mechanism to measure interference in order to avoid the excessive overhead involved in active network state gathering phenomenon. This metric is based on a cross layer design. The metric consists of two components namely **Inter_load** to capture interflow interference and **CSC** to capture intra-flow interference. The interflow interference is captured by measuring the signal strength values that can measured by the commodity wireless cards. The parameter Interference ratio (IR) is defined which is the ratio of SINR to SNR. The channel busy time parameter which is defined to be the time that a packet spends in the wireless medium for successful transmission is also used in the Inter_Load component to account for load awareness on neighbouring nodes which could possibly cause interference to the ongoing transmissions. The channel busy time (CBT) that considers both the backoff time and the time that no data keeps the channel busy is calculated using idle period.

$$CBT_i = \frac{(Total\ Time - Idle\ time)}{Total\ Time}$$

$$Inter\_load_i = ((1 - IR_i) * \zeta) * CBT_i$$

where $0 \le IR \le 1$ and $0 \le CBT \le 1$.

$$IR_i = \frac{SINR_i}{SNR_i}$$

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The intraflow interference is computed using the channel switching cost component(CSC). The definition of CSC says that higher weight has to be assigned for paths with consecutive links using same channel than paths that alternate their channel assignments. This component favours more channel diversified paths.

Authors in [12] built a transmission interference model by determining the transmission contention degree of each link as a function of wireless link loss and quantifying the impact of wireless link loss on medium access backoff. It is explicitly addressed that transmission interference is highly dependent upon wireless link loss rates. Then the optimality of IEEE 802.11 medium access scheduling is also considered in the transmission interference model. A parameter called **Transmission contention degree** (TCD) of a link is defined to capture interference. TCD(k) is defined as the average time the outgoing queue of a node k is not empty over a given time period. Since the packets queued at the outgoing queue could be a possible hindrance for other nodes to transmit it proved to be a crucial parameter to calculate the level of interference.

In order to accurately estimate the link performance cross layering was employed by authors in [13] to gather wireless channel information. The metric proposed was named **ELP (Expected link performance metric)** in which the desire to choose routes that are likely to pass through dense regions of the network is not encouraged. Cross layered channel information at MAC layer in neighbouring nodes is used to accurately determine interference. Medium congestion and collisions due to hidden stations are the major sources of interference in wireless networks. An estimate of the medium congestion around a node is defined by a factor named **Interference factor(IF)**.Periodic probing of the MAC to find if it is busy is an estimate of medium congestion. The medium occupancy(ie.busy state) is either an indication of a node receiving packets or the existence of communication between other nodes(ie) Network allocation vector pending. The fraction of times the medium is busy compared to the observed window is an estimate of medium congestion.

$$IF_A = \frac{MAC\ Busy_A(Rx) + MAC\ Busy_A(NAV)}{Total\ Time}$$

The interference factor at the receiving node B also includes the time the medium is busy due to its own transmission.

$$IF_B = \frac{MAC\ Busy_B(Rx) + MAC\ Busy_B(Tx) + MAC\ Busy_B(NAV)}{Total\ Time}$$

The link interference from node A to B is given by the maximum of the interference factors at nodes A and B.

$$IF_{AB} = Max(IF_A, IF_B)$$

The main consideration to improve radio resource utilization is to devise an intelligent method to tackle interference. The traffic situation of the adjacent nodes is an important parameter to account for interference as proposed in [14]. The nodes at the interference range of a given pair of source and destination are compelled to wait for the medium to be cleared before gaining access to the same due to the broadcast nature of wireless medium. If all the nodes of the mesh network send data through good links there is a high possibility of performance degradation due to the onset of congestion due to interference and due to the added traffic from other nodes through overlapped paths. Hence transmitting data with a knowledge of interference measured by considering the traffic load among adjacent nodes gain importance. Although knowledge of DCF MAC procedure of 802.11 was used to record interference, packet delay is defined to be the time interval from the time a packet is at the head of its MAC queue ready for transmission, until its successful reception in the destination. The authors analyzed the consequence of nearby nodes traffic load on ETT at sending node, receiving node and intermediate point of link. A measurement of transmission delay was done by increasing the nodes that generate traffic load and it was justified that an increase in the traffic of interfering nodes causes an average increase in end to-end delay of sending (TX), receiving (RX) and intermediate (Link)nodes .It is a well known fact that the average MAC delay is proportional to network traffic. It was also recognized that the end to end delay is not the same in the intermediate link as in the source and the destination nodes when the number of interferers is the same. To overcome such an issue overhearing of RREP packets was done by the neighbouring nodes to record the condition of interference.

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Capturing interference at the MAC layer is important because if any two nodes interfere at MAC layer they cannot both transmit simultaneously. The degree of interference is dependent on the transmission rate. Conversely if the nodes are too far apart (ie. absence of MAC layer interference) that one node's transmission does not influence the carrier sense behavior of other then the transmission of one node happens to be an interference for the other node. The transmission rate of the sending node is affected by the above phenomenon. Such a type of interference can be addressed by considering the multi rate model [14].The work in [14] captures intra and interflow interference in a unifying manner. The authors proposed a MAC layer throughput model for wireless channel access by specifying three types of intervals namely successful transmission interval, collision interval and an idle interval. The type of physical layer encoding employed and RTS/CTS mechanism used in DCF affects the duration of these three intervals. The authors addressed a significant property of wireless networks as a station with a low transmission rate affects not only its own throughput, but the throughput of all stations in the same network. In scenarios of low contention degree the probability that a node contends for channel access holds an inverse proportionality to the minimum contention window. The packet length of the packets traversing the set of links that can interfere with transmission on the link of interest is an importance parameter to be considered for analyzing the throughput of the link. The packet length on the link of interest is also used for throughput estimation. Hence the packet length of the interfering links contributes for the estimation of channel occupancy (ie. interference level) and this was considered by authors in the design of C**ontention aware transmission time metric (CATT)**[15] .

The radio resource utilization in wireless networks can be enhanced by the efficient management of interference effect among the neighbouring links .Many of the interference reduction algorithms aims to minimize the number of links .The authors indeed proved that path selection in terms of bandwidth or loss rate is prone to cause a sever deterioration of the quality of the remaining available resources in the network. This deterioration is due to the resulting interference in the network. Hence the authors in [16] devised **Interferer Neighbours count (INX)** to select a path that alleviates the resulting interference in order to preserve good paths for the subsequent arriving connections. This was accomplished by considering the bit rates of the interfering links as a parameter of importance to capture the interference level. This knowledge enabled a better interference free path selection for subsequent arriving connections.

The authors in [18] defined a parameter by name channel utilization at a node which they defined to be the fraction of the channel time in which the channel is sensed busy by a node. The channel utilization at a node is dependent on the number of bits at the physical layer sent by another present in the carrier sensing range of the node of interest during a certain time interval and also on the data rate at which the bits were sent over the physical layer. The authors stressed that contentions among nodes sharing the same radio channel and Frame error rate of the wireless links are the critical parameters to determine the quality of the wireless link. A slight modification to the MAC layer was introduced to capture the interference level. The idea to trace in the MAC layer, the set of nodes through which the frame has passed was adopted to eliminate intra flow interference. To perform this every node must be given an identifier. To reduce the storage space required if the MAC address of wireless interface is used as identifier the concept of generating the ID using hash function with MAC address as input was adopted. An additional field by name passing_nodes_set (P_set) that records all the nodes through which the frame have travelled has been introduced. Another set named child_nodes_set (C_set) is also maintained by each node which denotes the set of nodes from which frames are sent through the node of interest. Information in *P*_setand *C*_set helps a node to determine if the frame being sent on the channel belongs to one of the flows handled by this node or not.

The authors in [19] proposed a route management framework by name **FIRM** addressing the throughput degradation phenomenon of existing flows due to the entry of new flows.They have made use of the interference and carrier sense relations into the design of the routing metric.The routing metric calculation involves the use of available path bandwidth which is calculated using the available link airtime.The authors define two matrices namely contention matrix which is also called as the carrier sense marix and hidden interference matric.As the focus of our study in this paper is interference a definition of hidden interference matrix alone is done below.The authors have defined the hidden interference matrix $H : E * V \rightarrow [0,1]$ where E is the set of links and V is

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the set of nodes.It is defined that each wireless link e_k has a set of hidden interferers

$$N_{int}(e_k) = \{v_i \in V | h_{ki} > 0\}.$$

It is obvious from the definition of hidden interference matrix that when two nodes V_a and V_i transmit simultaneously only(1-h_{ki}) portion of V_a's transmission is correctly received by V_b(ie. The desired transmission is between the nodes V_a and V_b).Also the authors have paid attention to only data-data interference as the interference contribution by other factors like data-ack,ack-ack,and ack-ack is considerably low.

5. CONCLUSION

In this paper an analysis of the different types of interference is presented. Also the definitions of terminologies namely the transmission range, interference range and carrier sensing range was reviewed. A thorough knowledge of these terminologies is essential for understanding and modeling wireless interference. The various parameters namely number of interfering nodes, data rate of neighbouring links etc which could be a potential source for estimating the interference levels was analyzed. It is observed that attention must be given to the effects of MAC layer contention to estimate interference accurately. This paper would serve as a platform to perform more research activities in analyzing the different other parameters to estimate interference in wireless mesh networks.

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