A Review of Cluster-Based Congestion Control Protocols in Wireless Mesh Networks

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Abstract

Packet loss in Wireless Mesh Networks (WMNs) is due to congestion and probably due to high bit error rate caused by interference, link and node failures. Presently, congestion control and routing protocols in WMNs are not seen to have tamed this recurrent problem of congestion being experience most times in the wireless network. Routing techniques may lead to a co ngestive scenario and the congestion control should detect and probably avoid such situations. The way in which the congestion is handled may results in longer delay and more packet loss and a very significant overhead may also be incurred. Hence, this study takes a cl oser look at existing solutions with the application of clustering techniques to solve routing and congestion control problems because it offers scalability and reduced overheads. The study further exposes the weakness and added advantages of some of these cluster based solutions which can assist researchers to come up with broader approach to tackle the inherent problems of congestions and load balancing in an ad hoc network like WMNs. The paper conclude with a planned future research to device an appropriate level of tradeoff between computational overheads of cluster-based routing and high network throughput, low latency and delay while solving congestion problems.

Keywords: *Wireless Mesh Networks (WMNs), Routing, Congestion Control, Load Balancing, Packet Loss, Throughput.*

1.0 Introduction

A wireless mesh networks (WMNs) is a communications network made up of radio nodes organized in a mesh topology.WMNs are dynamically self-organized and self-configured, with the nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity[1]. The coverage area of the radio nodes working as a s ingle network is sometimes called a m esh cloud. Access to this mesh cloud is dependent on t he radio nodes working in harmony with each other to create a r adio network. A mesh network is reliable and offers redundancy. When one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more intermediate nodes.WMNs are comprised of two types ofnodes: mesh routers and mesh clients. Other than the routing capability for gateway/bridge functions as in a conventionalwireless router, a m esh router contains additional routing functions to support mesh networking.

Wireless mesh networks have a relatively stable topology except for the occasional failure of nodes or addition of new nodes. The path of traffic, being aggregated from a large number of end users, changes infrequently. Practically all the traffic in an infrastructure mesh network is either forwarded to or from a g ateway, while in ad hoc networks or client mesh networks the traffic flows between arbitrary pairs of nodes[22].

In any networks, congestion occurrence is a co mmon phenomenon, this is when resource demands in the network exceed the capacity the network can provide and the packets loss is experienced. This has been a menace that many authors have proposed different solutions based on the topologies and applications need. Recent approach to solve the congestions problem in WMNs adopts cluster based solutions.

The purpose of this study is to reveal the strong and weak points of some of these cluster based solutions so that researchers can come up with broader approach to tackle the inherent problems of congestions and load balancing in an ad hoc network like WMNs. The rest of this paper is structured as follows. Section 2 discusses network congestions in both wired and wireless mesh networks. Section 3 discusses various clustering algorithmtechniques and some implementation strategies for these clustering. In section 4, greater attention is paid to some existing work on cluster-based routing and congestion control algorithms in WMNs and section 5 concludes the paper and proposed a future research plan in our attempt to join the league of researchers working to solve congestion problemsin WMNs.

2.0 Computer Network Congestion

Congestion occurs when resource demands in a network exceed the capacity the network can provide.[29]identifies some factor that contributed to congestion in a network to include network topology, number of flows, traffic characteristics of the flows and their routes as well as channel capacity and the available transmission rate at the physical layer.

Put more formally, if, for any time interval t, the total sum of demands on a network resources is more than its available capacity, then, the network resources is said to be congested for that time interval, i.e.

∑demands > available resources

As network users come and go, so do the packets they send, hence, the network performance is therefore largely governed by these inevitable natural fluctuations. In a network with shared resources, where multiple senders compete for link bandwidth, it is necessary to adjust the data rate used by each sender in order not to overload the network. Packets that arrive at a router and cannot be forwarded are dropped, consequently an excessive amount of packets arriving at a network bottleneck leads to many packet drops. These dropped packets might already have travelled a l ong way in the network and thus consumed significant resources. Additionally, the lost packets often trigger retransmissions, which mean that even more packets are sent into the network.

Thus network congestion can severely deteriorate network throughput. If no appropriate congestion control is performed this can lead to a congestion collapse of the network, where almost no data is successfully delivered. Such a situation occurred on the early Internet, leading to the development of the TCP congestion control mechanism [19]. However, to guarantee continuous network usage at all times and also to reduce wastage due to resources used in transmitting loss packets from their original source to the congested node, it is imperative to have a congestion control mechanism that will tackle head-on the menace of congestion occurrence in the networks. The major goal of congestion control mechanism is simply to use the network as efficiently as possible by attaining the highest possible throughput while maintaining a low loss ratio and small delay [33].

2.1 Congestion in Wireless Mesh Networks

Like any other network topologies, congestion occurs in WMNs whenresource demands in the network exceed the capacity the network can provide and packets loss is experienced. Though, the packet arrival rate at an intermediate node depends on the traffic model of the flows as well as on the available route, if a node is on the route of many flows, there is higher probability of such node suffering from congestion compare with a node with less flows on its route. This analogy is usually the case for nodes that share link with gateways in a multihop mesh network.

Nevertheless, packets loss may also be noticed in wireless networks because of the lossy nature of channel, and this loss may be caused by factors such as interference, path fading,node and link failures. Link failure occurs frequently in mobile ad hoc networks, since all nodes are mobile. As far asWMNs are concerned, link failure is not as critical as inmobile ad hoc networks, because the WMN infrastructureavoids the issue of single-point-of-failure. However, due towireless channels and mobility in mesh clients, link failuremay still happen.

Unfortunately transmission control protocols (TCP) that is saddled with the responsibilities of congestion control among other functions takes all packet drop as a signal for congestions, this has made classical TCP congestion control mechanisms to be inadequate for wireless networks brand. Many TCP variants were developed to improve the performance of the traditional TCPs to tackle some noticeable problems such as non-congestion packet losses due to link failure, interference, and path fading, because the traditional TCPs do n ot differentiate congestion and non-congestion losses. As a result, when non-congestion losses occur, the network throughput quickly drops due to unnecessary congestion avoidance. In addition, when wireless channels return to normaloperation, the classical TCP cannot be recovered quickly.

It is expected that most traffic flows aredelivered to/from the Internet in WMNs connected to theInternet. As a r esult, one or a few gateways and mesh nodes (MNs) locatednear the gateways may be congested due to trafficconcentration. This phenomenon is peculiar in WMNs. In aconventional WLAN, every access point is connected to thewired broadcasting media such as the Ethernet and has directone-hop access to the access point with the gateway function,so it does not require explicit congestion control mechanism, whereas, in WMNs, provisioning of explicit congestion control mechanism may be required to be able to handle diverse sources of congestions [29].

3.0 Clustering Algorithms

Cluster and clustering are words that are used broadly in computer networking to refer to a n umber of different implementations of shared computing resources [34]. Typically, a cluster integrates the resources of two or more computing devices that could otherwise function individually, together for some common purpose. Clustering of wireless network nodes into groups with proper cluster head (CH) selection will impose a regular structure in the network and makes it possible to guarantee basic levels of system performance such as throughput and delay, even in the presence of mobility, energy resources and a l arge number of mobile nodes. However, mobility and energy resources are not major issues in infrastructure WMNs. Cluster algorithms may be used in improving database access and network performance. The network performance metrics such as routingdelay, bandwidth consumption, energy consumption, throughput, and scalability [12] are highly improved with appropriate clustering techniques. A clustering algorithm splits the network into disjoint sets of nodes,each centering on a chosen cluster-head. Efficient clustering protocols rely on different designgoals, depending on the application they are designed for.

For the specific case of cluster-based congestion control and load balancing, there are a s et of properties [12] that must be considered when selecting aclustering algorithm among which are: scalability, convergence average packet loss, and stability.Since different clustering algorithms have different properties, each algorithm is suitablefor a different application. Some clustering algorithms have O(*n*) convergence time, where *n*represents the number of nodes in the network. Some algorithms like LCA [2], RCC [35], or CLUBS [25], are notscalable and cannot be implemented in wired or wireless networks with a l arge number of nodes. However, in the case of scalable algorithms, there are different choices concerning the applicationsand the formation of the cluster-heads.

Among the popular clustering algorithms in use are Lowest ID [14] algorithm guaranteesthat no cluster-head can be in the range of another. Highest Connectivity [26] is another clustering that was aimed to use highest connectivity nodes as cluster-heads. Other types of clustering algorithms calculate the weight of each node according to a specificmetric. Examples include MOBIC [6] whose metric isnode mobility, DCA and DMAC [3,4] that assignweight to nodes in function of its transmission range or node mobility, and WCA [8] that chooses its cluster-heads depending on the node battery, degreeof connectivity or transmission power according to the scenario. ACE [7] isanother clustering protocol that results in a highly uniform cluster formation, close to hexagonal.

The criteria used to elect cluster-heads in some of the referred algorithms consider mobility-related metrics to reduce frequent re-elections of cluster-heads. Nevertheless, to solve the problemof congestion control in wireless mesh networks, these mobility metrics are not of great concerns since WMNs are quasi static compare with other ad hoc networks.

3.1 Implementation Strategy of Clustering Algorithms

According to [15] the three possible implementation strategies of the clustering algorithms are: static, centralized and distributed clustering algorithms. Lots of scholarly publications abound on clustering and cluster head selection approaches for ad hoc networks. Some of these popular algorithms are based on random criteria such as the lowest identifier (LID)[14, 17], other clustering schemes are based on degree of connectivity and remaining battery power[20] and could be based on criteria such as nodemobility[32].
In the rest part of this paper, related works in clustering algorithms which are designed and implemented in several clustering techniques such as weighted clustering, hierarchical clustering and emergent clustering algorithms for effective and efficient load balancing, routing and congestions control.

3.2 Weighted Clustering Techniques

3.2.1 Lowest-ID Algorithm (LID)

Lowest-ID Algorithm was originally proposed by [14] and later reviewed by [17].This algorithm assumes that each node is assigned a distinct identifier (ID). Periodically, the node broadcasts the list of nodes it can hear, including itself. A node which only hears nodes with ID higher than itself is a cluster-head (CH), unless it specifically gives up its role. Consequently, the lowest ID a node hears is its cluster-head.

However, the algorithms suffers some drawbacks, the CH can delegates its duty to the next node with the minimum ID in its clusters; a highly mobile node with the lowest ID and the chain effect can both cause severe re-clustering. Again, this scheme is bias towards nodes with smaller ID which leads to the battery drainage of certain nodes and it does notattempt to balance the load uniformly across all the nodes.

3.2.2 Distributed Clustering Algorithm

The Distributed Clustering Algorithm (DCA) [3] is suitable for clustering ad hoc networks, in which nodes assumes quasi-static or moving at a very low speed. DCA uses weights associated with nodes in electing cluster heads. The DCA makes an assumption that the network topology does not change during the execution of the algorithm. A node waits for all its neighbors with higher weights to decide to be CHs orjoin existing clusters. Nodes possessing the highest weights in their one-hop neighborhoods are elected as CHs. Whenever a nodereceives multiple CH announcements, it arbitrates among these CHs using a preference condition (such as a node with higher weightwins). If none of the higher-weight neighbors of a node decides to become a CH, then this node decides to become aCH.

The protocol is fully distributed and efficient, as it exhibits some great features that make it scale large enough for wireless mesh network. It incurs very limited bandwidth cost since each node broadcasts one, and only one, message. This latter is sent when the node determines its cluster, thereafter, the algorithm stops. The iterative approaches experience the problem of convergence speed which is dependent on the network diameter(path with the largest number of hops). Despite slow iteration convergence speed, the performanceof iterative techniques is also highly sensitive to packet losses.

Distributive and Mobility-Adaptive Clustering Algorithm (DMAC [4]) was developed by modifying DCA protocol to allow node mobility during or after the cluster formation process.

3.2.3 Weighted Clustering Algorithm

The Weighted Clustering Algorithm [8] elects a n ode based on the number of neighbors. The algorithm takes into consideration the number of nodes a CH can handle ideally without any severe degradation in the performance, transmission power, mobility, and battery power of the nodes. Unlike other existing schemes which are invoked periodically resulting in high communication overhead, the algorithm is adaptively invoked based on the mobility of the nodes. Computation cost is reduced by CH election procedure as long as possible while load balancing is achieved by specifying a predefined threshold on the number of nodes that a CH can effectively handle. W hile this guarantees that none of the CHs are overloaded at any instance of time, the load balancing factor (LBF) to measure the degree of load balancing among the CHs is generated as a performance metrics. This algorithm helps to control congestion; however, node mobility computation will severely affect the overhead cost and may even introduce enormous traffic that may cause congestion in WMNs.

3.2.4 Enhanced Weighted Clustering(EWCA)

Based on weighted clustering algorithm (WCA, [8]), enhanced WCA was proposed by [28]. The enhancement depended on two factors: improving the load balancing and performing the stability in the network. The load balancing is accomplished by determining a p re-defined threshold on the number of nodes that a CH can effectively covered. This ensures that none of the CHs are overloaded at any point of clustering process. The algorithm stability was achieved by reducing the number of nodes detachment from its current cluster and connects to another existing cluster. The result from several simulations shows that the protocol provides better performance in terms of stability of the created clustered topology, load balancing and number of cluster head change.

3.2.5 Generic Distributed Clustering

A generic distributed cluster-based middleware for infrastructure WMNs was proposed by [15] which was aimed at decreasing the bandwidth cost of application protocols by delegating and distributing some specific tasks to cluster heads, while it also enhance the network reactivity and response delay. The algorithm of middleware is generic and acts as a co mmonbasis for different kinds of distributed applications. The middleware is made up of two layers i.e. the core layer which builds and maintains the multi-cluster architecture in an effective way (the clustering service) and the second layer, which acts as an interface with the applications. However, each type ofapplication requires a specific adaptor (application adaptor). Thislatter defines the role and tasks of each node (cluster heads vs.cluster members) within the distributed application.The authors were able to show through several simulations that the algorithm shows the lowestbandwidth cost. This assertion is confirmed even in highly connected environments where the other clustering schemes have competitive performances; the use of acluster-based middleware if combined with efficient clusteringalgorithms may significantly reduce the bandwidth usage ofdistributed applications inside the wireless mesh backbone.

However, the algorithm was not application specific; neither does it conceptually and contextually tackle congestion problems in wireless mesh networks.

3.3 Emergent Clustering Algorithms

In the work of [21], the paperpresented an energy efficient and scalable TDMA-based MAC layer clustered protocol for sensor networks. The work is an example of emergent clustering algorithms. The scheme handles dynamic changes in the network topology and limits the control packet overhead. Scalability is achieved through network clusters. The algorithm was validated through simulation and it was shown to have positive impact on energy consumption and other contemporary network performance metrics.

Algorithm for Cluster Establishment (ACE) [7] employs an emergent algorithm. ACE consists of two logical parts. While the first logical part controls how clusters can spawn, the second rules over how clusters migrate dynamically to reduce overlap. As nodes can start the protocol in different times, this is an asynchronous protocol. Nodes only initiate actions at random intervals to avoid collisions. However, they respond to other nodes messages when they are received. During the protocol execution a node can have three states, namely un-clustered (i.e. a n ode that does not followany of the clusters), clustered (i.e. a node that follows one or more clusters) or it may be a cluster-head (cluster leader). The formation of clusters is done in a self-elective process. Each node waits for its next iteration and then it takes an action depending on its state.

After a p re-defined number of iterations (normally 3 iterations, a number experimentally determined to yield good results) the algorithm is ready to terminate. If a node is a cl uster-head it terminates immediately and informs its neighbors. If a node is clustered, it waits until its cluster-heads have terminated and then it chooses one randomly.

Another approach to clustering is dynamic cluster architectures [9] which offer several desirable features. Formation of a cluster is triggered by certain events of interest (e.g., detection of an approaching target with acoustic sounds). This algorithm requires no explicit leader (CH) election; hence, no excessive message exchanges are incurred. When a node with sufficient battery and computational power detects any signal that is of interest to it (with a high signal-to-noise ratio, SNR), it volunteers to act as a CH. As more than one "powerful" nodes may detect the signal, multiple volunteers may exist. A judicious, decentralized approach has to be applied to ensure that only one CH is active in the vicinity of a target to be tracked with high probability. Nodes within the vicinity of the active CH are "invited" to become members of the cluster and report their node data to the CH. In this manner, a cluster is only formed in the area of high event concentration. The authors devise and evaluate a fully decentralized, light-weight, dynamic clustering algorithm for single target tracking by focusing on acoustic target tracking, though the authors claimed protocols can be readily applied to other types of tracking applications.

The algorithm may not perform well in WMNs since it was designed to manage energy efficiency due to power failure normally experience in WSNs. The protocol will impose more overhead on WMNs, and may not scale well because of the centralized approach used to ensure only one cluster head is active at target node vicinity, also, the computation algorithms release more traffic that could cause congestion into the network.

3.4 Hierarchical Clustering Techniques

Hierarchical or tree-based clustering is aneffective way to manage nodes that are characterized by large number of nodes which has crucial effect on traffic load, bandwidth resource availability, dynamic changes of topology, etc. Themanagement of these nodes could be in a singlehierarchy with few hundred nodes which may or maynot have CHs or multi-level hierarchies with thousandsof nodes organized in several levels incorporatingordinary nodes, CHs and cluster boarder gateways, such multi-level hierarchies can be found [23, 24, 30].

3.4.1 Hierarchical State Routing (HSR)

In some application specific hierarchical clustering protocols, falls the Hierarchical State Routing (HSR) [18] which is a multi-level cluster-based hierarchical routing protocol. In this protocol, mobile nodes are grouped into clusters and a CH is elected for each cluster. The CHs of low level clusters again organize themselves into upper level clusters, and so on. Inside a cluster, nodes broadcast their link state information to all others. The CH summarizes link state information of its cluster and sends the information to its neighboring CHs through the cluster boundary gateway nodes. Nodes in upper level hierarchical clusters flood the network topology information they have obtained to the nodes in the lower level clusters. In HSR, a hierarchical address is assigned to every node. The hierarchical address reflects the network topology and provides enough information for packet deliveries in the network. In HSR, logical addresses reflect the group property of mobile nodes and hierarchical addresses reflect their physical locations. Combining these addressing schemes can improve adaptability of the routing algorithm.

It was however not exploiting the multipath routing to achieve load balancing and lessen network congestions. The logical and hierarchical addressing of the nodes may impose high overheads on the network.

3.4.2 Low Energy Adaptive Clustering Hierarchy (LEACH)

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [16] is also an application specific clustering protocol, which has been shown to significantly improve the network lifetime. It is one of the most popular hierarchical routing algorithms for sensor networks. It uses two-layered architecture for data dissemination. It is a cl uster-based protocol that uses local data fusion and classification to greatly reduce the amount of information that must be transmitted to the base station. LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. In this scheme, nodes periodically elect CHs and broadcast an invitation message for nearby nodes to join the cluster. The energy load of being a CH is evenly distributed among the nodes by incorporating randomized rotation of the high energy CH position among the nodes.Each non-CH node determines its cluster by choosing the CH that requires the minimum communication energy.

LEACH is completely distributed and requires no global knowledge of network. The clustering process involvesonly oneiteration, after which a node take a decision either to become a C H or not. However, the issues with LEACH are the use of single-hop routing where each node can transmit directly to the CH and since the decision to be the cluster head is probabilistic, there is a good chance that a node with very low energy gets selected as a cl uster head which may run out of energy within shortest time frame.

4.0 Existing Clustered Congestion Control Protocols

There are lots of rich literatures on cluster based congestion control algorithms CBCC [37], DCRP [27], CRP [31], EWCA [28], QoS-aware Node Clustering and Tax-based Subcarrier Allocation [11], ACP [13]. These algorithms exploit the advantages of clustering as highlighted by [36] which include among others scalability, reduction in communication overheads for both single and multi-hop, transmission of aggregated data for reducing number of nodes taking part in transmission and reduction in useful energy consumption.

4.1 Cluster Based Congestion Control (CBCC) Protocol

Cluster Based Congestion Control (CBCC) protocol [39] was developed for mobile ad-hoc networks. This algorithm consists of scalable and distributed cluster-based mechanisms for supporting congestion control in ad-hoc networks. Nodes were grouped into clusters and messages are exchanged between cluster head and their associated nodes, while nodes perform local computations of estimated traffic load the estimated information is processed by the cluster head and a collective cluster level load estimate is transmitted to the cluster heads towards the source clusters. This allows source nodes to regulate their sending rate based on the congestion level in traffic path.

The goal of [39] was to acquire macroscopic network statistics using a heuristic approach to define the traffic rate estimate for the network which helps in performing rate adjustment for the control of the sending rate of the source nodes. A current load threshold was defined to establish whether or not congestion exist in a traffic path. This threshold assists a node to transmit its computed value to the cluster head only if it exceeds the set threshold. The author claims that the scheme improvesthe responsiveness of the system when compared with end-to-end approach such as AODV and Congestion Aware Routing protocol for Mobile Ad Hoc Networks (CARM)[10]. The result from the author's simulation shows that CBCC protocol is highly efficientin dealing with multiple flows by achieving good packet delivery ratio, high throughput and low delay.

Nevertheless, the algorithm will impose high overhead on WMNs because of the computational cost of mobile nodes re-clustering since it was originally designed for mobile ad hoc networks. It will not as well be able to perform effective load balancing without a multipath routing metrics.

4.2 DTH-based Cluster Routing Protocol

The main goal of the DTH-based cluster routing protocol (DCRP) [27] was to achieve high scalability in topologies where the mobility of the mesh point is low or even zero, in which case, a s calable network will tolerate fault and reduce congestion conditions. The protocol proposed path selection using distributed hash tables and RA-OLSR. DCRP partitions a WMN into clusters with each cluster having its own identity. This cluster is made up of mesh points MPs.

The MPs in a cl uster execute an intra-cluster routing protocol to exchange routing information for the routes to MPs within the cluster. The intra-cluster routing help reduce the total amount of routing information exchanged since all other information for other MPs in other clusters are not included. This reduction in information exchange will be more effective in topologies where the MPs are mostly immobile and stations are highly mobile by frequently changing the mesh access point (MAP). In other to support communication among nodes in different clusters, the DCRP uses an inter-cluster routing protocol. The protocol is executed only by the MPs of the cluster that are connected to MPs of other clusters. These MPs are called cluster's boarder MPs while MPs in a cluster that are connected only to MPs of the same clusters are called internal MPs.

A DCRP uses centralize clustering algorithm approach, though simple and is likely to lead to better clustering decisions, because they are based on complete knowledge of the network topology. However, this algorithm may not scale well enough with a network topology that has large number of nodes like WMNs.

4.3 Cluster-Based Routing Protocol (CRP)

Cluster-Based routing protocol (CRP) was proposed by [31] for wireless mesh network. The authors devise alternative strategies for routing against broadcast techniques used in the previous route request to entire nodes in the network. They gave some extra power and responsibility to mesh portalpoint (MPP) and cluster head of each group. The network partitioned into the clusters help reduce the initialbroadcast to all nodes. As each cluster has one cluster headthat have all information of its neighbor and so path requestonly multicast to different cluster heads only. The scheme distributes the whole mesh network into groups of clusters.

Mesh point portal (MPP) assigned one node as a cluster head(CH) of each cluster group and stored the cluster headinformation in its own table such as CH id, CH neighborsetc.Each CH has some extra authority compare toothers cluster member. Each CH has two tables, the first table stores the information of neighborsCHs while second table stores the information about cluster groupmember which is assigned by the MPP. Every cluster memberstores the information of his CH. When a normal clustermember wants to communicate with any destination node, itsends path request (PREQ) message to his CH, while the CH check its own group member list. If the destination exists in the same group, it sends path reply with path information quickly and source node starts transmission according to that path. If destination node belongs to other cluster, CH sends PREQ message to mesh portal and the mesh portal multicast PREQ message to all CHs.

The scheme uses MPP multicast during path discovery foronly once while unicast is used in all remaining transmission messaging. Hence it reduces power consumption and improvesthe network performance. Mesh portal and cluster headperiodically updates own table that helps to detect any change. Despite the simplicity and effectiveness, there is no measure to control congestion either adaptively or dynamically.

4.4 EnhancementWeighted Clustering Algorithm (EWCA)

In EWCA [28] cluster head election, CH is adaptive invoked based onmoving of nodes or changing the relative distance between the nodesand CH. Election is repeated until all nodes must be either a member of any cluster or as a CH. For the algorithm to handle load-balancing, assume that there are a p redefined thresholdnumber of mobile nodes that a cluster can cover. The distributed mobility infrastructure on each nodes serves as the server for the mesh nodes toestablish communication channel that is based on Transmission Control Protocol/internet Protocol(TCP/IP) sockets [37, 38]. When the numbers of cluster's members are too large, that may produce a small number ofclusters which make bottleneck of a MANET and reduce systemthroughput. Moreover, too-small cluster's member may produce alarge number of clusters and thus resulting in extra number of hops forsending a p acket from source to destination, and longer end-to-enddelay. The two conditions aggravate congestive situation in a wireless networks. When a cluster size exceeds its predefined limit, CH electionprocedure is repeated to adjust the number of mobile nodes in that cluster.

If the distance between CH and cluster members is within thetransmission range, that will result into a better communication. The relative distance between nodes affects the consumption of thebattery power.It is known that more power is required tocommunicate through a larger distance. Since CHs have theextra responsibility to send packets to other nodes, they consume more energy than ordinary nodes.
One of the challenges of MANET is mobility. This is a very strategic reason for network topology change. A goodelected CH will not move too often since CH movement will lead to faster movement of nodes from its cluster to join another cluster. This imposed extra computational cost for election of CH in the new cluster and reduces network stability. There are many mobility models known such asRandom Way Point Model (RWP), Random Way Point on BorderModel (RWBP), Random Gauss Markov (RGM) model, andReference Point Group Mobility model (RPGM). However, the mobility concept is of no interest to this research. Because this protocol was designed for MANET, it is difficult to directly implement this in WMNs due to different networking characteristics and design objectives. Hence, it will impose high overhead and low throughput on the network due to its mobility feature.

4.5 QoS-aware Node Clustering and -basedSubcarrier Allocation

The deployment of WMNs is relatively permanent since node mobility is low. This feature has giving rise to the requisite of high efficiency of WMNs with QoS support. Therefore, a n ew clustering approach which was specifically tailored for QoS-sensitive WMNs is seen to be indispensable by [11]. For efficiently support of multimedia services and enhancement system capacity, effective channel assignment andinterference control are important in facilitate QoS provisioning and reuse of frequency. This factor prompted the authors to propose a distributed channel allocationstrategy tailored for a clustered mesh backbone is crucial. To reduce the computational complexity of channel allocation, the authors' approach is to solvethe clustering problem and to allocate subcarriers in successionalternatively. Considering the factors of system capacity, QoS provisioning, burden on cluster heads, delay of packet delivery, and the bursts wireless environment, clustering problem was formulated by setting an upper bound on the subcarriers allocated to a cluster. With clustering, interference control and hence frequencyreuse can be facilitated by channel allocation via clusterheads. QoS-aware clustering algorithm with tax-based subcarrier allocation tailored for WMNs was found to showing achievement of a high systemthroughput, and provide a good performance tradeoff betweenpacket delay and end-to-end transmission rate for real-timetraffic.

The algorithm was shown through simulation to be vital to bolster frequency reuse, effectively ameliorating the system throughput for a mesh backbone while it also provides a g ood performance balance between packet delay and end-to-end data rate for real-time traffic, resulting into a viable candidate for QoS provisioning. However, the scheme does not consider multi-path transmissions which could have aided congestion avoidance or control.

4.6 Adaptive Clustering Protocol (ACP)

Adaptive clustering protocol (ACP) [13] presented an algorithm for cluster establishment. Unlike clustering algorithms with main objectives of most of which are basically to ensure all nodes are clustered, clusters are of uniform size and energy consumption is minimized, the objective of ACP is to dynamically adapt the size of the clusters to the prevailing network conditions, such as node density, and traffic conditions, such as the sending rate while it was also aim to ensure reliability in spite of collisions/interferences. In order to achieve the goal, the authors developed a g eometric-probabilistic model that describes the expected coverage of a one-hop communications as a function of range, sending rate and density, which was used to design Adaptive Clustering Protocol (ACP) that efficiently adapts to network conditions, such as node density and load; and user requirements, such as reliability.

The algorithm consists of two logical parts - the first deals with the formation of clusters and the second deals with dynamically reconfiguring the clusters to take into account the network dynamics. The protocol was based on hexagonal packing, while the arm length of each hexagon is same as the range of the nodes. This was done to ensure that all nodes in a cluster are within the transmission range of a n ode at the center of the hexagon. Thus, if nodes are not present at the optimal strategy locations, the coverage figure will get distorted; moreover, the distortion effect may spread.
The major advantages of the protocol are:
(i) Scalability of more number of clusters with network density; i.e., the number of clusters required does not increase with the density;
(ii) Communication within nodes generates very low overhead, i.e. no *hello messages* are required, while performance is comparable to other protocols;
(iii) Adaptive Cluster Protocols (ACP) adapts to network conditions and user requirements, it h as low overhead and saves network life by balancing energy.

Nevertheless, the protocol fails to adaptively or dynamically perform congestion avoidance, congestion control and load balancing for the wireless network.

5.0 Conclusion and Future Work

In this paper, we tried to expose the strong and weak points of some of these existing cluster based solutions for routing and congestion control in wireless mesh networks. Though the lists are not exhaustive, but we are tactical in the discourse approach to some of these fundamental algorithms for clustering. We conclude that many of these clustered solutions are found wanting in solving congestions problems in WMNs without modifications to their original forms. Some are in an attempt to improve routing techniques, imposed more overheads and introduce more packets to the network which results in nodes bottlenecks and network congestions.

The bottom line is that, our future work will find a way of reaching an appropriate level of tradeoff between computational overheads and high network throughput, low latency and delay. We will focus on the propensity of using Distributed Clustering Algorithm (DCA) as basis for developing an adaptive intra and inter cluster congestion control scheme forsustainable, effective and efficient congestion avoidance and control in WMNs.

Acknowledgments
The authors wish to acknowledge Universiti Teknologi Malaysia for provisioning of enormous research facilities and also, the financial support provided by the Federal Polytechnic Ede, Nigeria and Education Trust Fund (ETF), Abuja, Nigeria ishighly appreciated.

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