BRAC UNIVERSITY

THESIS REPORT

Thesis topic

Hybrid Wireless Mesh Network

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Abstract

In the last few years, there has been an immense influence of wireless networks in our daily life. Especially, wireless mesh network has got a prominent attention in academic research and commercial deployment as well.

We are proposing Hybrid Wireless Mesh Protocol (HWMP) to enhance the performance of wireless mesh networks as statistic shows that for WMNs, the proposed routing protocol outperforms other well-known protocols in terms of different parameters like packet delivery fraction, network throughput and end-to-end delay.

HWMP defined in IEEE 802.11s, is a basic routing protocol for a wireless mesh network. It is based on AODV and tree-based routing. In HWMP, on-demand routing protocol is used for mesh nodes that experience a changing environment while in a fixed network topology proactive tree-based routing protocol is an efficient choice for mesh nodes .

Moreover, wireless mesh networks provides facilities such as ease of installation, cost effective deployments, a high level of performance in coverage area and capacity, network flexibility and self-configuration capabilities. These benefits enable seamless communication in underdeveloped areas such as rural communities. Congestion control and optimal route selection in the network layer is gained through routing protocol optimizations.

Here, Network simulator 3(ns-3) has been used to simulate our particular protocol in the simulation model. Simulation (ns3) results show that the proposed hybrid wireless mesh protocol (HMWP) significantly improves the performance of wireless mesh networks than other protocols.

ACKNOWLEDGEMENTS

To my parents (mom and dad), you did a big sacrifice by sending me BRAC university for getting higher education. Your sacrifice was beyond measures to me. Without your brave step, it would become impossible for me to complete my education. I am really very thankful to both of you and will always remember your sacrifice. I would also like to thank my supervisor, Sadia Hamid Kazi , without her guidance and support; I cannot be able to achieve my goal. She never denied helping us in difficult time. In the end I would also like to thank my group partners, without their cooperation it was difficult to achieve the target

---Md. Saleh Ahmed

Definitely all praises be to Allah. So, first of all, I express our deep gratitude to the Almighty Allah who created and nurture us in this transitory world. I also have to put our heartfelt respect and gratitude for His kindness and help that were provided to us to complete our report on the topic ***"Hybrid Wireless Mesh Network".***
Then I would like to express thanks to our supervisor, Sadia Hamid Kazi (Senior Lecturer, Department of CSE, BRAC University). Her candid suggestion, patient, enthusiastic encouragement thought out the have made this attempt successful. Her insight and invaluable remarks left distinct of the work. To her generosity, our gratitude is unbounded.

---Foez Md Iqbal Hossain

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Chapter 1-Introduction

1.1 Background

A wireless access point is used to create a wireless mesh network (WMN), and it can be installed at each network user's location. Each network user is actually a provider also, which forwards data to the next node. As each node need only transmit as far as the next node so the networking infrastructure is decentralized and simplified .Wireless communication is bringing a huge amount of use these days and is still becoming popular from times immemorial. This is because of the demand of the latest technology these days, arising from laptops, wireless devices such as wireless local area networks (LANs), etc. As the popularity of this is rising day by day, so it made wireless commutation data rates higher and making the price relatively cheaper, thus wireless communication is growing so fast. Wireless communication can actually work between hosts by two different types of methods; one method permits the existing network carry data and voice, and second method provides the host to communicate with each other by making an ad-hoc network. Wireless Mesh Networks (WMNs) are actually one types of ad-hoc networks and this Ad-hoc networks are often called as mobile ad-hoc networks (MANETs). For making large coverage area of wireless local area networks companies now a day's use wireless mesh networks. Actually WMNs are consisted of wireless nodes and each node having its own packet. By forwarding packets to one another these nodes can communicate with each other. This is very much similar to MANETs where each node acts as a router and a host, which is mainly a wireless router. In WMNs, if clients wish to communicate with routers, they actually use the networking interfaces like Ethernet 802.11 and Bluetooth. Most wireless network installations now a day have a set of access points which have overlapping coverage zones, and each access point having connected to a wired network. By having few of the access points connected to a wired network they eliminate the wired connectivity, and making the others to forward packets over multiple wireless hops. In this thesis only comprising on the area of wireless mesh networking. Low cost wireless routers are making peoples life easy these days. The simplicity in deployment at home or office, and the liberty in the ability to connect that they provide, have made wireless routers ubiquitous. Without requiring every access point to be physically connected to the Internet, these networks can simply be deployed inside a building, campus, on a large geographical area. Routing protocols have great significance in WMNs. Without these routing protocols WMNs cannot really be implemented. In a network the communication made between the routers is done by routing protocols. They actually work on the third layer of the Open System Interconnection (OSI). Routing loops and selecting preferred routes are done by them. Certain parameters might be encountered by Lot of routing protocols during the communication process such as delay, jitter, throughput, latency and network load in WMNs. Researchers are still working on this specific issue on finding an appropriate and efficient protocol that can serve best performance under these certain conditions.

1.2 Objective of this thesis

Our first objective of this thesis is to evaluate the performance of wireless mesh networks using Hybrid wireless mesh network protocol (HWMP) with other well-known protocols like AODV in terms of different parameters and mobility to see whether our proposed protocol is well-fitted or not.

After that our second objective is to implement these protocols into the same simulation model to get the results that we are supposed to get when we will physically implement these protocols into an environment.

Then our final objective is to interpret the graphs that are being generated from the results in order to evaluate the performance with the specified parameters and mobility and we will get to know which protocol is better in most cases.

1.3 Related Work

This paper comprises of protocols that are being tested for delay, throughput and network load altogether. By keeping in mind about the conditions that is overhead, optimal path etc, the simulation of different type of protocols has been done on the software NS-3. We tested the routing protocols in WMNs for throughput, delay but we also added something more by testing the three parameters (delay, throughput and network load) together in our thesis project, and its simulation has been done on NS-3. Furthermore, routing protocols used in our paper were AODV, HWMP. Between these two protocols AODV and HWMP are actually a reactive type protocols.

Chapter 2- introduction to networks

2.1 Wired vs. Wireless Networks

The network that uses wires is known as a wired network. Wired LANs use Ethernet cables and network adapters. Two computers can be directly wired to each other using an Ethernet crossover cable though wired LANs generally also require central devices like hubs, switches or routers if there are more than two computers in a network. The installation of a wired network has been a primary issue because the Ethernet cable should be connected to each and every computer that makes a network. However in new homes nowadays, the wiring is being done in such a way that it will look like as it is a wireless connection, greatly simplifying the process of cables. [23]At the same way, wired network's wiring depends on things like what type of devices are being used in a wired network whether the network is using external or internal modem, the type of that internet connection and so on. In the wired network's configuration, the main test is the hardware implementation. Once the hardware implementation is done in a wired network, the rest of the steps in a wired network do not vary that much from the steps in a wireless network. There are some advantages of wired network that include cost, reliability and performance.[24]To build a wired network, Ethernet cable is a must thing because the creators of Ethernet cable continuously improving its technology and always creates a new Ethernet cable by removing the drawbacks from the previous version. In terms of performance, wired networks can always provide good results. Firewalls are the first and foremost security consideration if any wired LAN connected to the internet. Firewalls aren't supported by the Wired Ethernet hubs and switches. Therefore, firewall software products like Zone Alarm can be installed on the computers themselves. Broadband routers offer equivalent firewall capability built into the device, configurable through its own software. However solution for this is installing firewall software on each individual computer in a network [19].

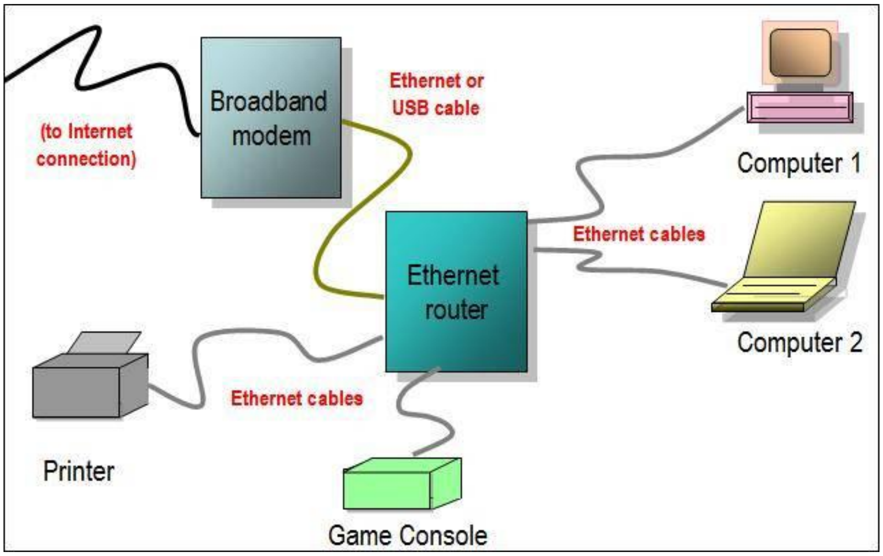

Figure 1. Wired Network

The nodes of wired network does require power, as they get that power from the alternating current (AC) source that is present in that particular network.

2.2 Wireless Networks

On the other hand, wireless network is such kind of network that does not use wires to build a network. It uses radio waves to send data from one node to other node. Wireless networks lie under the category of telecommunications field. It is also known as wireless local area network (WLAN). It uses the Wi-Fi as a standard of communication among different nodes or computers. There are three types of Wi-Fi communication standard. They are :

- 802.11b
- 802.11a
- 802.11g

802.11b was the oldest standard that was being used in WLAN. After 802.11b, the standard being introduced was 802.11a [19]. It offers better speed than122 previous one and is mostly used in business networks. The latest standard is 802.11g that removes the deficiencies of previous two standards [23]. Since it offers best speed from other two standards, also it is the most expensive one.802.11g is backwards compatible with 802.11b, meaning that 802.11g access points will work with 802.11b wireless network adapters and vice versa.

Pros of 802.11g - fast maximum speed; signal range is good and not easily obstructed.

Cons of 802.11g - costs more than 802.11b; appliances may interfere on the unregulated signal frequency.

802.11g is an amendment to the IEEE 802.11 specification that extended throughput to up to 54 Mbps using the same 2.4 GHz band as 802.11b. This specification under the marketing name of Wi-Fi has been implemented all over the world. The 802.11g protocol is now Clause 19 of the published IEEE 802.11-2007 standard and Clause 19 of the published IEEE 802.11-2012 standard.

Wireless LAN costs more than the wired network as it requires wireless adapters, access points that makes it three or four times expensive than Ethernet cables, hubs/switches for wired network. Wireless network also faces reliability problem like wired networks because during installation process, it might be encountered with the interference that can come from microwave ovens, wireless phone and others household products. Wi-Fi communication standard's performance is inversely proportional to the distance between the computers and the access points. Larger the distance between the computers and access point, smaller will be Wi-Fi performance and hence smaller will be performance of wireless network. Similarly, security wise it is less secure than the wired network because in wireless communication, data is sent through the air and thus there are more chances that data can be intercepted [19].

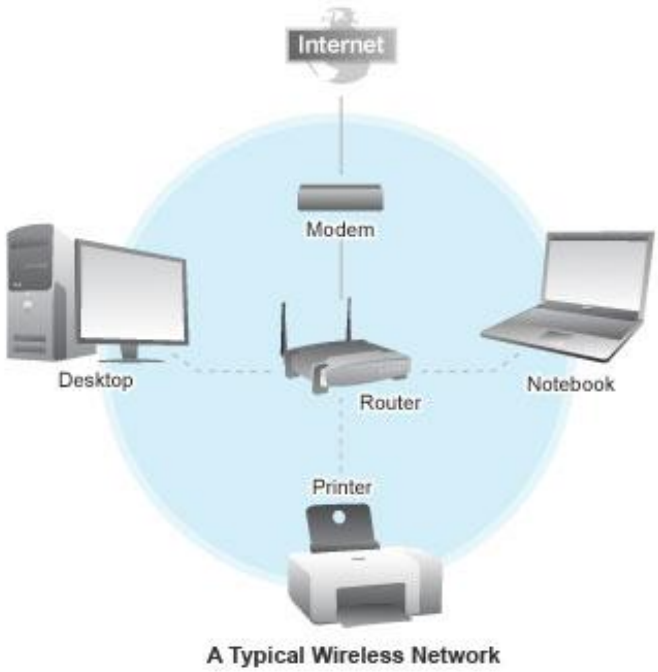

Figure 2. A wireless network

2.3 Nodes and Links

Devices that are in a communication network are known as nodes and the connection between these nodes is known as a link. On an IP network, a node is any device with an IP address in a mesh network the nodes are unfeasible with the interconnection of the nodes. We require one, three and six links in order to connect two nodes, three nodes and four nodes respectively. It means there is no direct relationship between the number of nodes and therein between links in a mesh network. Initially a physical interface was required by nodes for connection with each link and this interface performed parallel to serial and serial to parallel conversions because at that time data flows bit by bit on a serial link. In a mesh network every node has physical constrictions that put limitations on the number of nodes that are to be connected [18].

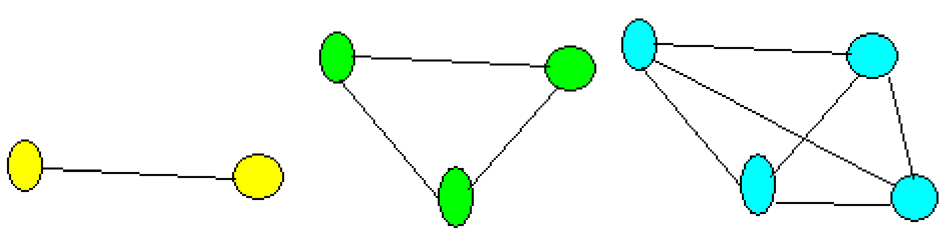

Figure 3. Nodes and Links in Mesh Network [18]

Chapter 3- introduction to Wireless mesh network

3.Wireless mesh network

A wireless mesh network (WMN) is referred as a communications network made up of radio nodes structured in a mesh topology. Wireless mesh networks generally consist of mesh clients, mesh routers and gateways. The mesh clients are usually laptops, mobile phones and other wireless devices while the mesh routers forward traffic to and from the gateways which might be connected to internet but not needed actually. The coverage area of the radio nodes that forms a single network is sometimes denoted as mesh cloud. Accessing this mesh cloud is not independent on the radio nodes working altogether with each other to create a radio network. A mesh network is reliable and offers redundancy. When anode can no longer operate due to failure, the rest of the nodes can still be able to communicate with each other directly or through one or more intermediate nodes. One of the major advantages of wireless mesh networks is that it cans self form and self heal. Wireless mesh networks can be implemented with various wireless technology including 802.11, 802.15, 802.16, cellular technologies or combinations of more than one type. [20]

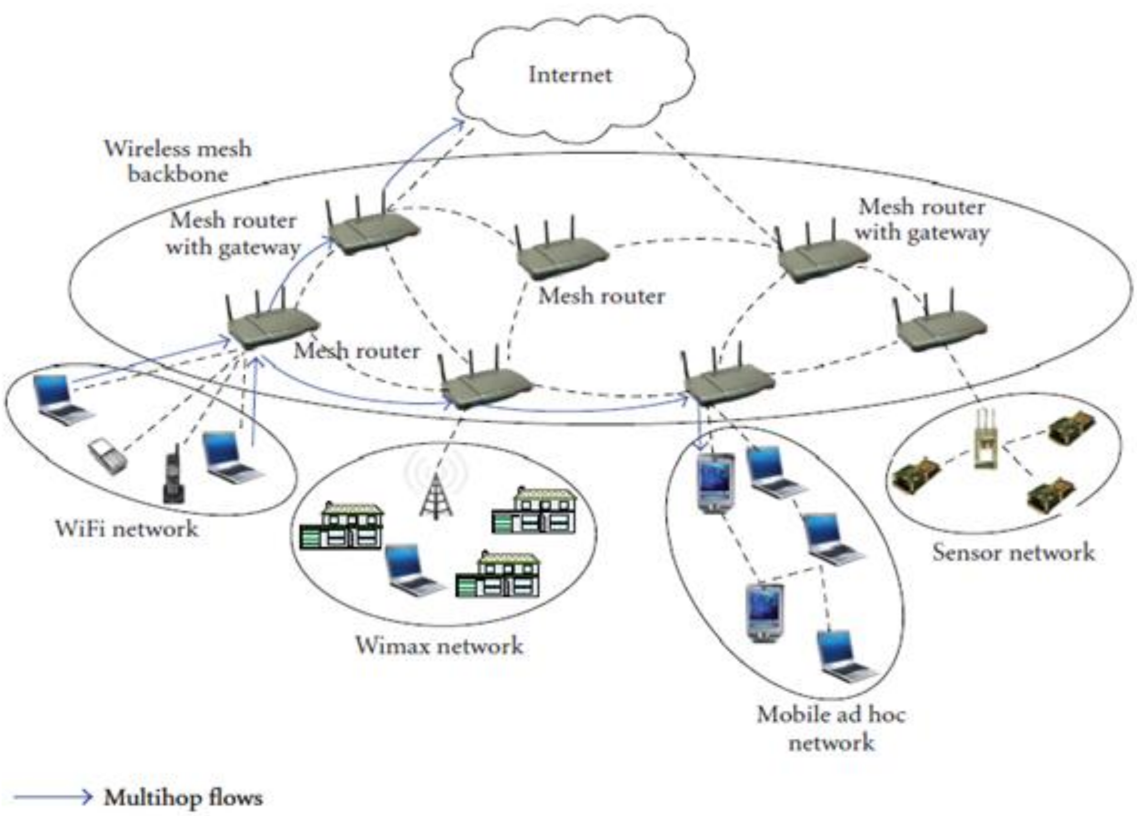

Figure 3. A wireless mesh network

3.1Advantages of wireless mesh network

The advantages of WMN over other networks are very significant and have great deal of importance. There are some unique features compared to other network in WMN. These features are explained below:

- It doesn’t use wire.
- It is less cost effective.
- The more we provide nodes, the more we get speed.
- Beneficial for Non Line of Sight (NLOS).
- There is no need for network administrator.
- The data processing is pretty fast.
- Easy installation and uninstall.
- It doesn’t require new Wi-Fi standard.
- It’s tolerant to any faults.

Building a network without any wire brings a great deal of advantage. In most the case bigger network don’t really use any wire. The internet we use in our daily life is a realistic example for this. It is seen that most of the network are inter connected with each other wirelessly creating a mesh topology which is also called seamlessly [17].

It is cheap as it don’t use any wire.

It is very useful for those networks where there is no direct communication between sender and receiver and those types of communications are called NLOS communication.

In WMN the nodes automatically adjust themselves according to the situation, so there is no need for network administrator if there is a problem regarding nodes or the network.

WMN nodes can communicate with their neighboring nodes as well without going back to the central device, which increases its data processing speed.

According to the requirement WMN nodes can be installed or uninstalled.

Like all other wireless networks standards, WMN also uses one of those standards. Being a new technology it does not require new Wi-Fi standard.

WMNs are very much tolerant to faults, if couple of nodes in a network fails, the communication will always keep on going.

3.2Network structure

3.2.1Architecture

Wireless mesh architecture is a initial step to provide cost effective and also dynamic high-bandwidth networks over a particular coverage area. In the recent year, wireless local area networks (WLANs) have become very much popular and well known .The standard for WLAN is IEEE 802.11. This specification actually defines or specifies a physical and an Ethernet like MAC layer for wireless links [13]. IEEE 802.11 having mobile stations (STAs) and access points (APs) in it. A mobile station can be explained as a network device which is consist wireless network interface card. To provide connectivity to stations APs are acting as bridges. Wired links are used to connect from one APs to other APs. Wireless mesh architectures infrastructure is actually, a router network minus the cabling between nodes. It's actually built of peer radio devices that need not to have to be cabled to a wired port like WLAN access points (AP) do. Mesh architecture maintains the signal strength by breaking distances, which are long, into a series of shorter hops. The Intermediate nodes not only increase the signal, but they also make forwarding decisions based on perform routing that is knowledge of the network. So it is desirable to connect the APs via wireless links as well and thus we can create a WLAN Mesh. In WMNs, APs change by itself and provide the service of mesh access points (MAPs). Mobile stations are sometimes denoted as mesh clients. The new version of IEEE 802.11s standard for WMNs provides us a third class of nodes called mesh points (MPs) [14]. MPs and MAPs both support WLAN mesh services, providing them to forward packets, to extend the wireless transmission range, on behalf of other nodes. Mesh clients can communicate with MAPs but not with MPs. [11] There are three different types of WMNs; Infrastructure, Client and Hybrid.

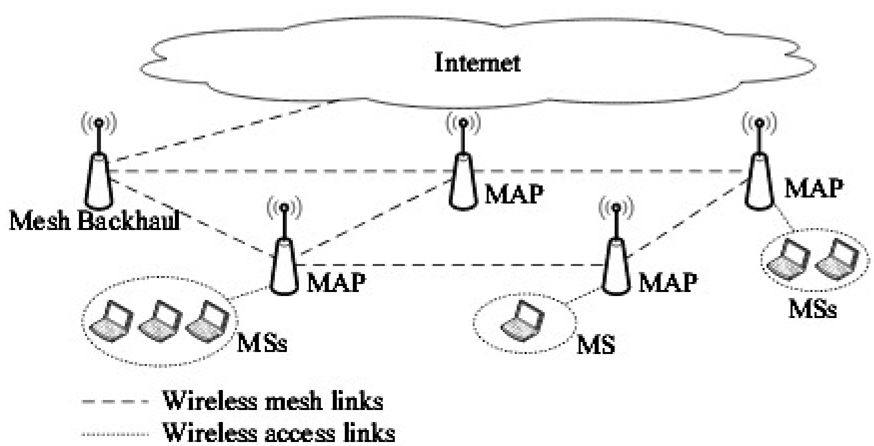

Figure 4. Architecture

3.2.2Infrastructure WMNs

WMNs infrastructure uses MPs and MAPs as the main backbone for the clients. Gateway availability like MPPs provides connectivity to external networks like Internet. The clients connect to the MAPs via standard 802.11 but they don't really forward packets. Nowadays this is the most important architecture. To increase coverage area access points are used. [11]

3.2.3Client WMNs

In this type of architecture layout, client nodes makeup the actual network so as to execute routing and configuration functionalities and also providing customers the end user applications. So as an example let us consider a collection of MPs which are actually connected with each other and thus can communicate with each other within the considered network and can forward data on behalf of others. In Client WMNs, a packet confined to a node in a specified network, hops from one node to other (multiple), to reach the desired destination. Furthermore, when comparing to infrastructure meshing the requirements on end-user devices is increased a lot. This is because in case of ClientWMNs, routing and self configuration must be performed by the end-users as an additional function. [11]

3.2.4Hybrid WMNs

The combination of infrastructure and client meshing provides us the architecture of Hybrid Wireless mesh network. Mesh clients can get access to the defined network by directly meshing with other mesh clients or can access through MPs. The infrastructure provides connectivity to other networks such as the Internet, Wi-Fi, WIMAX, etc. Inside the WMN, the routing capabilities of clients provide much more improved connectivity. This is the most applicable case that we are working is the hybrid architecture. IEEE 802.11s is one of the typical scenarios of Hybrid WMNs. It have clients (Ordinary stations), for accessing the network by using Mesh Access Points (MAPs) and we also have independent nodes (MPs) which can directly access the specified network. The total entries based on 802.11- based radio technology. Mesh networks have different necessity to the physical layer due to different type of system architecture. [11]

3.3Management

Infrastructure of this sector can be decentralized i.e. with no central server or centrally managed; both are relatively not very expensive. This is very much reliable and flexible, as each node only have to transmit as far as the next node. Nodes act as routers to transmit data from nearby nodes to peers , that are relatively far in distance to reach in a single hop, which provide a network that can span larger distances. The structure of a mesh network is a reliable one, as each node is connected to several other nodes. If one is inactive in a network, due to hardware failure or other reasons, then its neighbors can quickly track another route using a routing protocol. [2]

3.4Operations

The operation concept is similar to the way packets travel around the wired Internet--data will hop from one device to another until it reaches its destination. Dynamic routing algorithms implemented in such a way in each device that allow this to happen. Paths routing makes nodes aware of alternative paths between each other. An advantage of awareness of alternative paths is the fast recovery when a node or a link fails. If a node or link fails, the traffic can immediately be sent on an alternative path that does not contain the failed node or link. Another advantage with multiple paths is the possibility of balancing the traffic load. A multiple path routing mechanism can be node-disjoint or link-disjoint. Node/link disjoint path means that no node/link is a part of two different paths between the source and the destination. It is possible for a node to have more than one alternative path, but then a new path cannot contain a node (or link) that is a part of any of the other paths. Also, there exists braided multipath where an alternative path is a path not containing at least one node or link from the primary path. [15] [2]

3.5Applications

WMN is the first to introduce the concept of a peer-to-peer mesh topology with wireless communication between mesh routers. Many of today's deployment challenges have been greatly helped by this concept such as the installation of extensive Ethernet cabling and enable new deployment models. Some key application scenarios for wireless mesh networks are given below:

- WMNs can replace current 802.11 WLANs as the efficient choice for home networking
- Using WMNs in Campus environments (enterprises and universities), manufacturing, shopping centers, airports, sporting venues, etc will not only provide increased capacity but also robustness when a link fails and it will also provide network congestion.
- Wireless mesh networks can be installed quickly in the Military operations, disaster scenarios where the links of the normal communication are down.
- Mesh routers in different homes can be inter-connected thus it provides a community network with efficient applications like distributed file sharing and video streaming.
- Carrier-managed service in public areas or residential communities.
- These days U.S. military forces are using wireless mesh networking to connect their computers, mainly ruggedized laptops in field operations.
- Mesh routers can be placed anywhere such as on the rooftop of a home or on a lamppost to provide connectivity to mobile/static clients. Mesh routers can be added incrementally to improve the coverage area. [16] [21]

3.6 Multi-radio mesh

Multi-radio mesh is a unique pair of dedicated radios on each end of the link. It means a unique frequency is used for each wireless hop and thus a dedicated CSMA collision domain. It's a true mesh link where one can get maximum performance without any bandwidth degradation in the mesh and without increasing the latency. Hence, voice and video applications work just as they are supposed to work on a wired Ethernet network. There is actually no concept of a mesh in true 802.11 networks. There are only Access Points (AP's) and Stations. A multi-radio wireless mesh node will act as a station at one of the dedicated radios and connect to a neighbor node AP radio. [20]

3.6.1 Modern Mesh Networking

Modern mesh network works mostly on wireless and thus are called wireless mesh networking. In a wireless network each node has one Radio Frequency (RF) transmitter or receiver that always tries to communicate with all wireless nodes connected inside a network. Compared to wired networks RF has made the communication process pretty easy and flexible, this is because in wireless mesh network RF completes all the criteria for all the process of communication but in wired network it's opposite. This single interface has to be converted into multiple interfaces. Nodes should lie inside the range of transmission for the sake of successful communication [18].

3.6.2 Non Line of Sight

When there is no direct path for data transmission between transmitter and receiver, then it is called as the NLOS communication .There are actually some obstacles between the transmitter and receiver. The obstacles can be anything like tree, buildings, and mountains and so on. When transmitter sends out any data, it will be reflected from these paths and finally reaches the receiver. However NLOS is obtained or extracted from the term line of sight (LOS) that means there is direct communication between the transmitter and receiver and in between them there will be no obstacles. But in NLOS, a weak signal at the destination may be obtained when data reaches the receiver from different reflections surfaces. This term is known as fading. But fading brings a very minor problem these days though it can be reduced or bring to that level up to almost zero. In order to minimize/remove the signal fading, the most used way is to increase the bandwidth of that signal and increase the strength of a signal at the transmitter side. Increasing the range of frequencies will increase the bandwidth of a signal. WMN is actually used for NLOS network structure as it's the best option. So in this process, during the transmission of data from one end to another; the data strength does not remain the same when it does reach to its destination. So WMN has the option to automatically configure and handle this kind of situation as well. It boosts up the signal strength to that level that it does not experience a fade at destination and this is done automatically. As WMN has dozens of nodes in it and for that reason nodes itself help to find a clear signal at the destination. This is the main advantage of this network from others. Only it has the capability of doing this.

Figure 5. None line of sight

3.6.3 Seamless Communication

Seamless communication is based on the concept of always best connected anywhere anytime. In a WMN, there are obviously many nodes and the objective of seamless is to always keep these nodes online no matter what change occurs. User should not be disconnected during the ongoing communication. This offers handover (HO) management and location management. HO management means to keep nodes connected when the position or direction will change. Location management means that network will find from where the node is connected to it. Since for NLOS networks WMN works better, mobiles that are wirelessly connected with some access points also include under the type of NLOS communication. Because signal from the base station experiences reflection from different things and then reaches mobile node. This means it is another advantage of WMNs that it also provides seamless communication. [25]

3.7Resource Management in WMN

In wireless mesh networks the main thing is to keep the users satisfied in terms of quality of service (QOS). Good quality is always desirable and this demand of the users is increasing every day. If a network provides quality service to their users then it's considered as a good and successful network. If a network can't provide QOS then the network is just useless. While building a network we need to keep in mind a few very important things so that the users can have the QOS in the network. Only then the network can be able to fulfill the requirement of QOS. The most important things that should be in the wireless mesh networks are:

3.7.1 Channel diversity and deployment

For enhanced network performance, it is highly desirable to have channel diversity to prevent wireless interference and support increased number of users [8]. To get channel diversity in WMN it is very much required to do channel deployment. It can be done by two methods; fixed channel allocation (FCA) and dynamic channel allocation (DCA). At present, DCA scheme is preferred. In DCA, the probability of call is comparatively low than FCA.

3.7.2 Routing

By following the routing the QOS requirement in WMN can be easily gained as it extends network connectivity to end users though multi-hop relays including the access points and the network gateways [8]. This is so far the best criteria in terms of having QOS in WMN. As statistics show that, this has been the best technique for getting QOS in WMN and thus it has led to lot of routing protocols.

3.7.3 Mobility Management

Another important criteria is achieving QOS in WMN is to do mobility management. It includes both hands off management and Location management. Handoff management is needed for keeping the nodes always connected when the node is changed from its place or direction. Location management is needed for watching the node that is connected with the network from which location. Wireless mesh networks must reconcile both aspects, while accounting for its multi-hop nature [8]

3.7.3.1 Constant position waypoint mobility

It is the Mobility model for which the current position does not change once it has been set up. To change it, we have to explicitly set it up again to a new value.

3.7.3.2 Random waypoint mobility

In mobility management, the random waypoint model is such a random model for which the movement of mobile users and how their location, velocity and acceleration change over time. Mobility models are used for simulation purposes when new network protocols are under the evaluation. It is one of the most popular mobility models to evaluate mobile ad hoc network (MANET) routing protocols because of its simplicity and wide availability.

In random-based mobility simulation models, the mobile nodes can move randomly and freely without any restrictions. To be more specific, the destination, speed and direction are all chosen randomly and independently of other nodes. This kind of model has been used in many simulation studies. [22]

Two variants, the random walk model and the random direction model are variants of the random waypoint model.

Chapter 4- routing protocols for WMNs

Different routing protocols are described below:

4.1 Destination Source-Routing Protocol (DSR)

DSR is an on-demand routing protocol that is based on concept of source routing instead of relying on the routing table at each intermediate device. In source routing algorithm, each data packet contains complete routing information to reach its destination. Nodes are required to maintain route caches that contain source routes information of which the node is concerned. There are two major phases in DSR which are the route discovery and route maintenance. For route discovery, the source node broadcasts a route request message that contains the address of the destination along with source nodes address and a unique identification number. Every node which receives this packet checks if it has route information to destination. If not, it appends its own address to route record of the packet and forwards the packet to its neighbors. A route reply is generated if the route request reaches either the expected destination or an intermediate node which has route information to the destination. DSR has route cache to maintain route information to the destination. Route maintenance is started when the route error packets are generated at a node and that erroneous hop will be cleared from the node's route cache, thus all routes containing the erroneous hope are cleared at that point. Main disadvantage of it is that it has increased traffic overhead as it contains complete route information in each of its data packet Which is degrades DSRs routing performance. [9]

4.2 Destination Sequence Distance Vector Routing Protocol (DSDV)

Unlike DSR, DSDV is a proactive (Table-Driven) unicast routing protocol based on classical Bellman-Ford algorithm. Each node in the network has a routing table which contains information on all possible destinations within the network that means it's a table-driven routing scheme. Sequence numbers are used to distinguish stale routes from fresh ones. To maintain Consistency, routing table must be updated periodically throughout the network. If two updates have same sequence number then the path with smaller metric is used to optimize the path.

DSDV protocol only supports bi-directional links. This is a Disadvantage. Another main disadvantage is even if there is no change in the network topology, there is still traffic overhead. It also maintains routes which are never used. [9]

4.3 B.A.T.M.A.N (The Better Approach To Mobile Ad-hoc Networking)

B.A.T.M.A.N is a proactive routing protocol. It discovers routes through flooding originator packets (OGM) [10].It is a routing protocol for multi-hop ad hoc mesh networks which is under development by the "Freifunk" community and intended to replace OSLR. The crucial point of this batman protocol is the process of decentralizing the information of the best route through the network i.e. no single node has all the data. This technique eliminates the need to spread information concerning network changes to every node in the network. The individual node only saves information about the "direction" it received data from and sends its data accordingly. Hereby the data gets passed on from node to node and packets get individual, dynamically created routes. The overall results a network that have collective intelligence. An experiment started in 2007 with the idea of routing on layer 2(Ethernet layer) instead of layer Instead of sending UDP packets and manipulating routing tables, it provides a virtual network interface and transparently transports packets on its own.

Its main advantage is calculations are not performed by nodes and major disadvantage is paths with better QOS may not be chosen.

4.4 Ad-hoc On-demand Distance Vector Routing Protocol (AODV)

AODV is a reactive on-demand routing protocol which builds on both DSR and DSDV. Additionally, AODV forms trees which connect multicast group members. So, it is capable of both unicast and multicast routing. AODV is an improvement on DSDV as it minimizes the number of required broadcasts by creating routes on demand basis. It is also an improvement on DSR as a node only needs to maintain routing information about the source and destination as well as next hop. Thus it greatly reduces the traffic overhead. The process of route discovery is similar to DSR. Route request (RREQ) packets are broadcasted for route discovery while route reply (RREP) packets are used when active routes towards destination are found. HELLO messages are broadcasted periodically from each node to its neighbors in order to inform them about their existence.

The main advantage of this protocol is having routes established on demand and that destination sequence numbers are applied to find the latest route to the destination and also the connection setup delay is lower. Another advantage of AODV is that it creates no extra traffic for communication along existing links. Also, distance vector routing is simple, and doesn't require much memory or calculation.

One disadvantage of this protocol is that intermediate nodes can lead to inconsistent routes if the source sequence number is very old and the intermediate nodes have a higher but not the latest destination sequence number, thereby having stale entries. Also, multiple Route Reply packets in response to a single Route Request packet can lead to heavy control overhead. Another disadvantage of AODV is unnecessary bandwidth consumption due to periodic beaconing.[6][2][7]

4.5 HWMP (Hybrid Wireless Mesh Protocol)

HWMP is a basic routing protocol for a wireless mesh network defined in IEEE 802.11s. It's based on AODV (RFC 3561) and proactive tree-based routing. It is actually based on AODV but using layer 2 routing instead of layer 3 routing. In HWMP, on-demand routing protocol is adopted for mesh nodes that is efficient for changing environment while proactive tree-based routing protocol is an efficient choice for mesh nodes in a fixed network topology. For route discovery, on-demand routing in HWMP uses expanding ring search to limit the flood of routing packets. Reverse paths are set up by Route Request packets (broadcast).For Route maintenance, Nodes monitor the link status of next hops in active routes. When a link break in an active route is detected, a route Error message is used to notify other nodes about the occurrence of the broken link. Route Error message is a broadcast message, thus it notifies quickly about the route failure. The proactive tree-based routing is used in the mesh network when a root node is configured. By having this root node, a distance vector tree can be built and maintained for other nodes in order to avoid unnecessary routing overhead for routing path discovery and recovery. In HWMP, a few nodes can be designated as "Root Mesh Points." These nodes broadcast their presence and provide short cuts for path requests, which speeds route discovery. Besides, On-demand routing and tree-based routing can run simultaneously. [1] [3]

4.6 HWMP vs. AODV

Among these protocols HWMP and AODV are known as the better protocol. HWMP is based in AODV but using layer 2 routing instead of layer 3 routing. Thus, one question might arise that is if this new layer 2 routing protocol proposed for mesh networks will work better than the traditional layer 3 routing. To answer this question these two protocols were configured to work under the same conditions and we evaluated their performance in terms of increasing nodes and transmission rates. We will use different mobility; Constant position mobility and random waypoint mobility to analyze the performance and comparison between them. Under which parameters both AODV and HWMP will be simulated have given next .

(a) AODV's Parameters

Hello interval	3 s
Route Request retry	5
Route Request rate limits	10 pkts/s
Node traversal time	40 ms
Next hop wait	50ms
Active route timeout	100 s
Black list timeout	5.599 s
Delete period	15 s
Timeout bu&#11;er	2 s
Net diameter	35
Net transversal time	2.799 s
Path Discovery Time	5.599 s
Max Queue Length	255
Max Queue Time	30 s
Allowed hello loss	20
Gratuitous reply	Enable
Destination only	Enable
Enable hello	Enable
Enable Broadcast	Enable

Table 1 : AODV's parameters

(b) HWMP Parameters

Random Start	100 ms
Route Request retry	5
PREQ Min Interval	102.4 ms
PERR Min Interval	102.4 ms
Active path timeout	100 s
Net transversal time	102.4 ms
Max Queue Length	255
PREQ Threshold	10
PERR Threshold	32
Data Threshold	5
DO Flag	Enable
RF Flag	Disable

Table 2 : HWMP's Parameters

Chapter 5-methodology

We will use the software NS-3.17 to simulate the hybrid wireless mesh protocol (HWMP) and AODV protocol in the implemented simulation model.

5.1 Network Simulator 3

NS-3 is a discrete-event network simulator for Internet systems. It is free software licensed under the GNU GPLv2 license and is publicly available for research, development and use.
It is a tool aligned with the simulation needs of modern networking research allowing researchers to study Internet protocols and large-scale systems in a controlled environment.

It is built using C++ and Python with scripting capability. C++ is wrapped by python.

Supported Operating System: GNU/Linux, FreeBSD, Mac OS X
We can use NS-3 in windows but we won't get all the functionalities as we get in the supported operating system and also the installation process in windows is very tricky. [4]

5.2 Running a program on NS-3

To run a program on NS-3, waf is required. Waf is a Python-based framework for the configuring, compiling and installing applications.

5.3 The syntax to run any NS-3 script is

./waf - -run filename , Its execute the script from the SCRATCH folder .

5.4 The Syntax for visualizing a script

Ns-3 uses netanim, pyviz, and nam for the visualization of script. [6]

./waf - -run filename --visualize

5.5 Tracing in NS-3

NS-3 generates pcap packet trace files. pcap files can be read and display through Wire shark. The acronym pcap (usually written in lower case) stands for *p*acket *ca*pture and is actually an API that includes the definition of a .pcap file format. The most popular program that can read and display this format is Wireshark (formerly called Ethereal). However, there are many traffic trace analyzers that use this packet format. There are many tools available for analyzing pcap traces. WireShark is widely used. [5]

5.6 The syntax for enabling pcap tracing

PointToPoint.EnablePcapAll ("output-filename");

5.7 Reading tracing output with Wireshark

Wireshark is graphical user interfaces which can be used for displaying these trace files. Using Wire shark wecan open each of the trace files and display the contents as if i had captured the packets using a *packet sniffer*. it is the best tool for collecting of experimental data, or for testing of some application which works via network. One can see which information transmitted in any packet, source and destination addresses and a lot of other things

5.8 Syntax for enabling Constant position mobility

mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");

5.9 Syntax for enabling Random waypoint mobility

mobility.SetMobilityModel ("ns3::RandomWalk2dMobilityModel", "Bounds", Rectanglelue (Rectangle (-xMin, xMax, -yMin, yMax)));

5.10Simulation Environment

The environment used in all the simulations is the one provided below. A long-distance path loss propagation model has been used.
Using this model, we predict the loss asignal encounters in densely populated areas over distance. [1] Its parameters are:

Type: Log-distance path loss
Reference Distance = 1 m
Exponent = 2.7
Reference Loss = 46.7 dB
In all different tests performed, the devices present the following characteristics:
CCA Threshold = -62 dBm
Energy detection Threshold = -89 dBm
Transmission and Reception Gain = 1 dB
Minimum and maximum available transmission level = 18 dbm
Reception Noise Figure = 7 dB

5.11Parameters for evaluating simulation model

The following parameters are needed for evaluating our simulation based on Hybrid Wireless Mesh Protocol (HWMP)

Average throughput: number of bits received divided by the difference between the arrival time of the first packet and the last one.

Average Packet Delivery Fraction (PDF): number of packets received divided by the number of packets transmitted.

Average end-to-end delay: the sum of the delay of all received packets divided by the number of received packets.

Average routing load ratio: the number of routing bytes received divided by the number of data bytes received. A value of 1 means that the same amount of routing bytes and data bytes has been transmitted.

5.12Implementing the Simulation

Now, it's time to implement the simulation in the same simulation model in terms of both constant position and random waypoint mobility. The testing produces results in the form of graphs using the important parameters that will explain the behavior of using a particular protocol. It's the most crucial part of the thesis report.

Chapter 6-Comparing HWMP and AODV's performance

6.1 Performance analysis with increasing nodes

6.1.1 Packet delivery fraction PDF

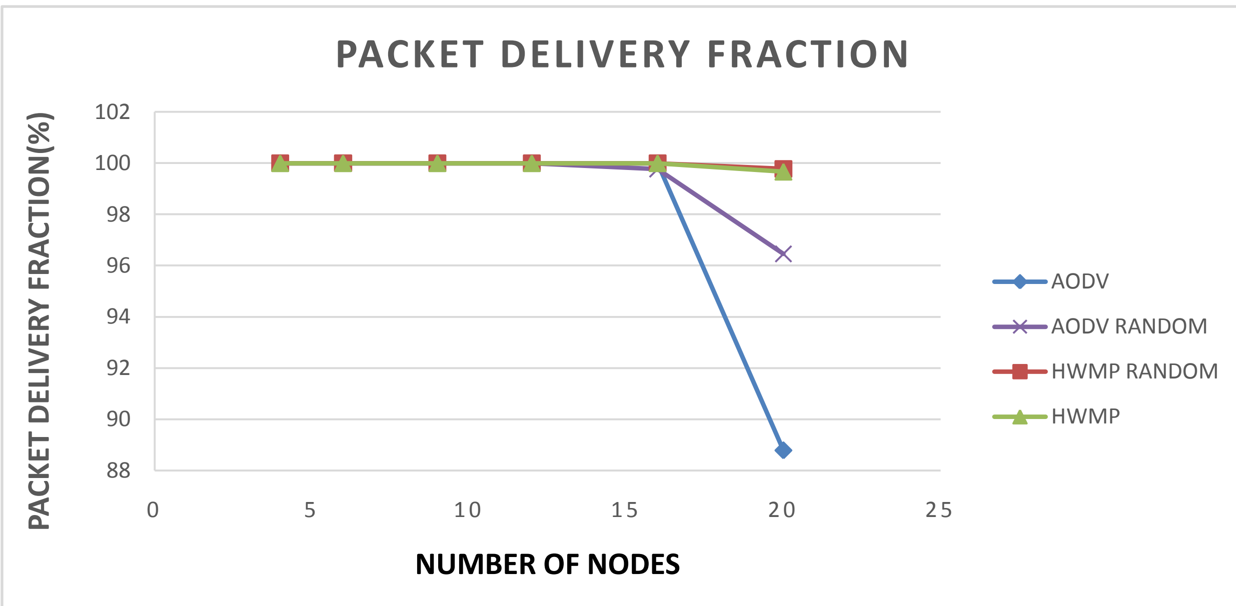

Figure 6. PDF vs. No. Nodes

As the number of nodes increases more routing traffic will be generated and as because AODV uses flooding for route discovery which will decrease AODV's packet delivery fraction (PDF) with the increasing nodes. AODV with random mobility slightly requires less traffic than AODV constant mobility.

HWMP re-routes traffic on the second optimum path to balance the traffic load when congestion occurs at intermediate nodes due to traffic from multiple nodes which leads the improvement of packet delivery fraction in HWMP protocol. HWMP with constant and random mobility both provides nearly the same performance.

6.1.2 Throughput

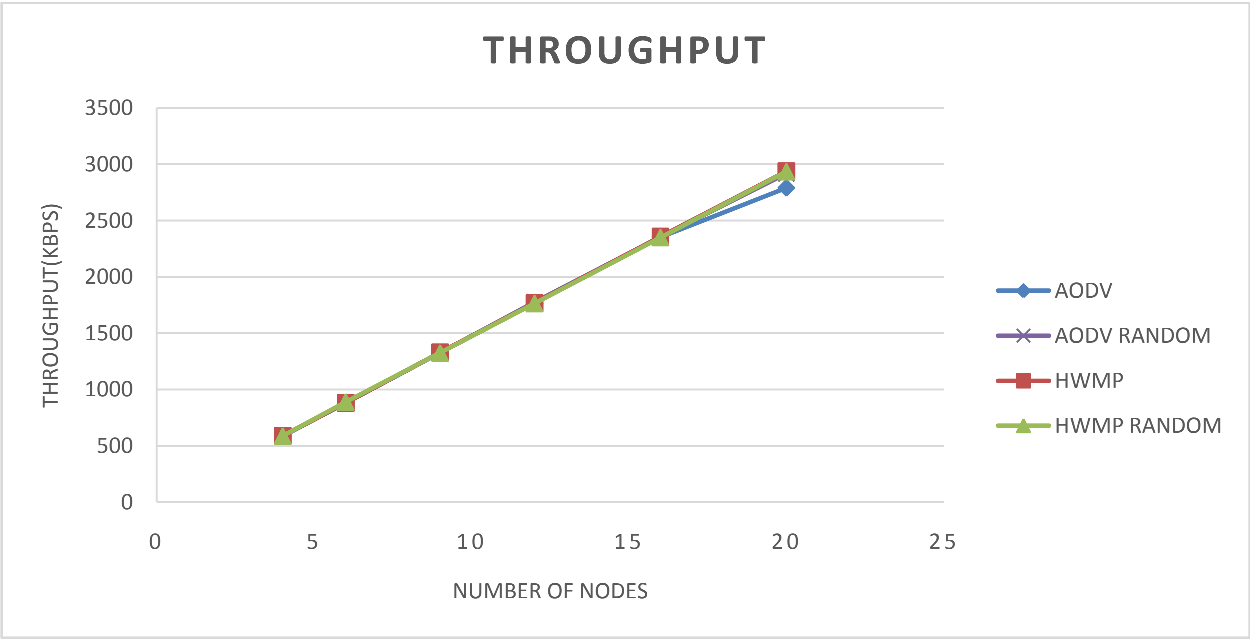

Figure 7. Throughput vs. No. Of nodes

When new nodes enter into the network, throughput of the network increases because more nodes are available to send/ share date with one another.

Increasing traffic load does not result in considerable fall of network throughput while sending the same data collection through AODV protocol in which nodes doesn't co operate like HWMP's nodes. Thus, AODV decreases network throughput.

HWMP outperforms AODV here because of its pro-active tree functionality. More nodes are available to send/share data with one another.

AODV random mobility also works better for the movement of nodes so nodes are available more whereas HWMP also works slightly nearer for the node mobility issue.

6.1.3 Average End to end Delay

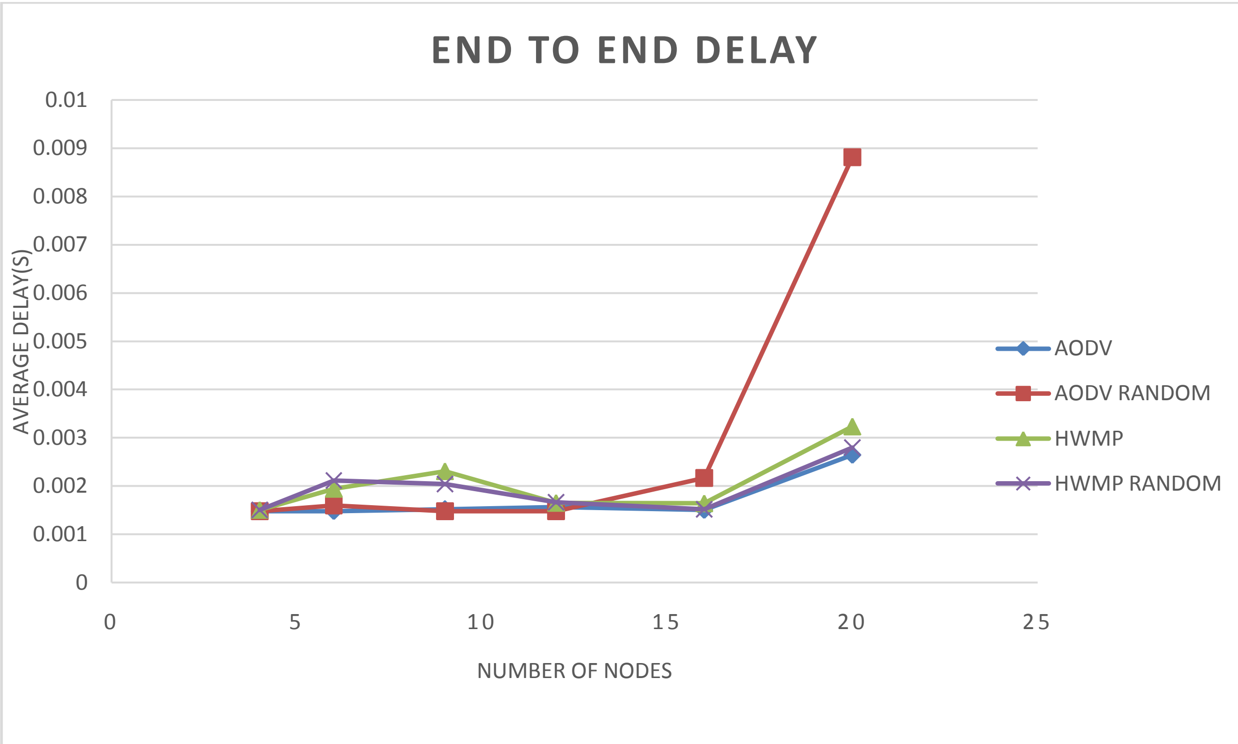

Figure 8. Delay vs. No. Of nodes

Generally delay increases by increasing the number of nodes. As in AODV, Route request (RREQ) packets are broadcasted for route discovery so with fewer nodes AODV doesn't work well but with more nodes AODV's route discovery mechanism works better. AODV with random mobility performs very bad as the node are moving. So it takes more time for route discovery but it performs nearly similar when the numbers of nodes are few.

Wherever In HWMP, a few nodes can be designated as "Root Mesh Points" as HWMP is based on pro-active tree-based routing. These nodes broadcast their presence and provide short cuts for path requests, which speeds route discovery. So it works pretty well for few nodes but if there are large numbers of nodes than under a root mesh there will be more nodes that slows up the performance.

HWMP with random mobility works better with more nodes than AODV with random mobility as nodes don't move that much from the pro-active tree.

6.2 Performance analysis n terms of transmission rates

6.2.1 When nodes =4, Packet Delivery fraction (PDF)

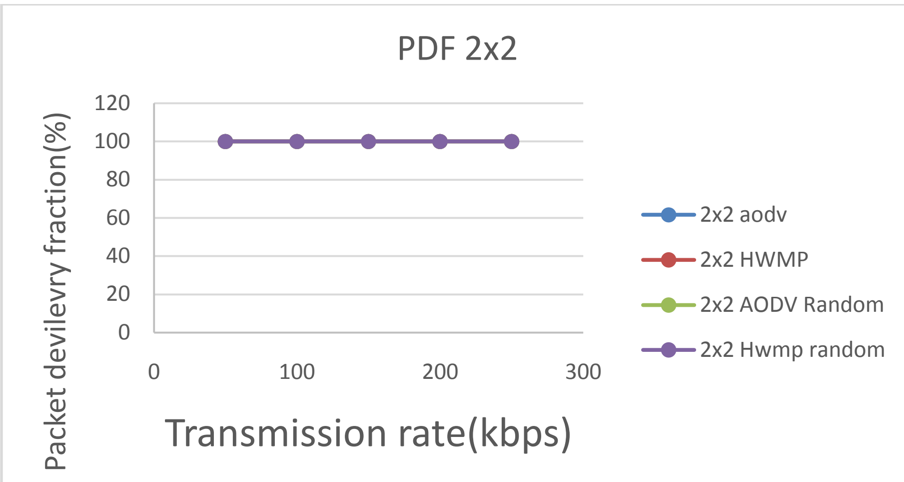

Figure 9. PDF vs. transmission rate (4 nodes)

In this case, all of these protocols give nearly the best performance.

6.2.2 When nodes =4, Total throughput

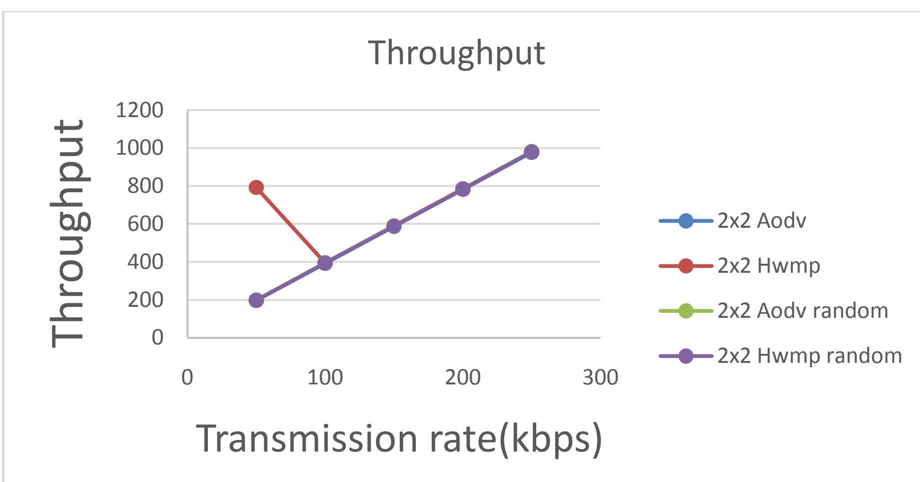

Figure 10. Throughput vs. transmission rate (4 nodes)

All these four protocols give same performance except for the HWMP constant position mobility.

6.2.3 When nodes =4, Average End to end delay

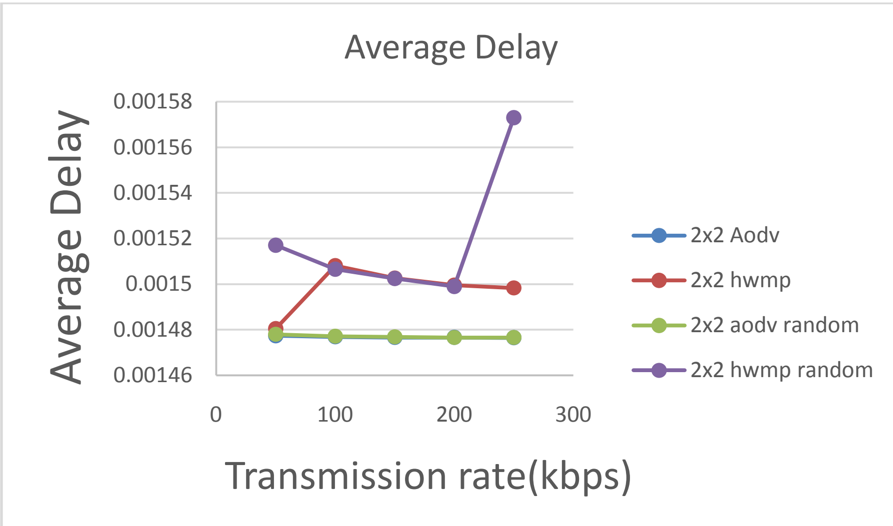

Figure 11. Delay vs. transmission rate (4 nodes)

Here, HWMP Random performs the worst. The best performance is given by the AODV with random mobility.

6.2.4 When nodes = 9, Packet Delivery fraction (PDF)

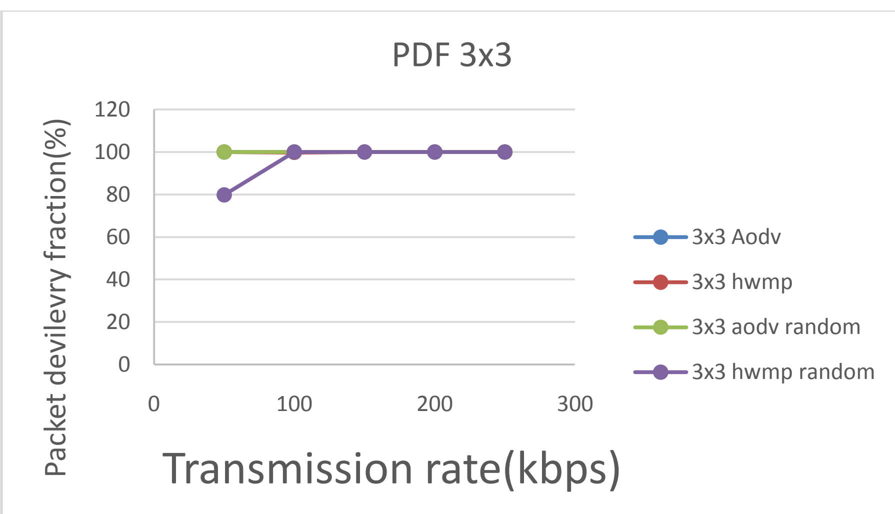

Figure 12. PDF vs. transmission rate (9 nodes)

Here, all of them perform nearly similar except for the HWMP with random mobility.

6.2.5 When nodes = 9, Total throughput

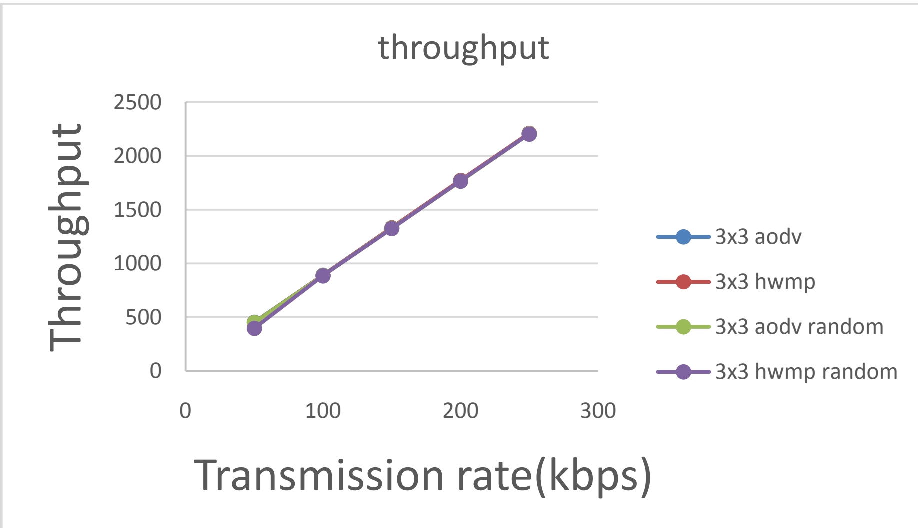

Figure 13. Throughput vs. transmission rate (9 nodes)

Here all of these protocols perform nearly same.

6.2.6 When nodes = 9, Average End to end delay

Figure 14. Delay vs. transmission rate (9 nodes)

Here, HWMP with random mobility performs better with low transmission rate while HWMP with constant mobility performs better at higher transmission rate. AODV constant position and random mobility perform nearly similar when the transmission is low. At higher transmission AODV with constant mobility performs the best.

6.2.7 When nodes =16, Packet Delivery fraction (PDF)

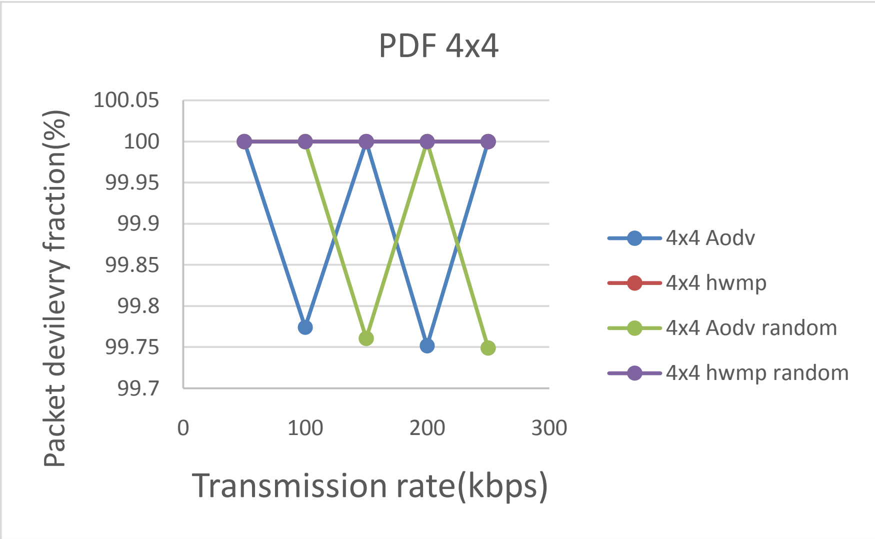

Figure 15. PDF vs. transmission rate (16 nodes)

HWMP with constant position and random mobility both perform better here than AODV and AODV random mobility.

6.2.8 When nodes =16, Total throughput

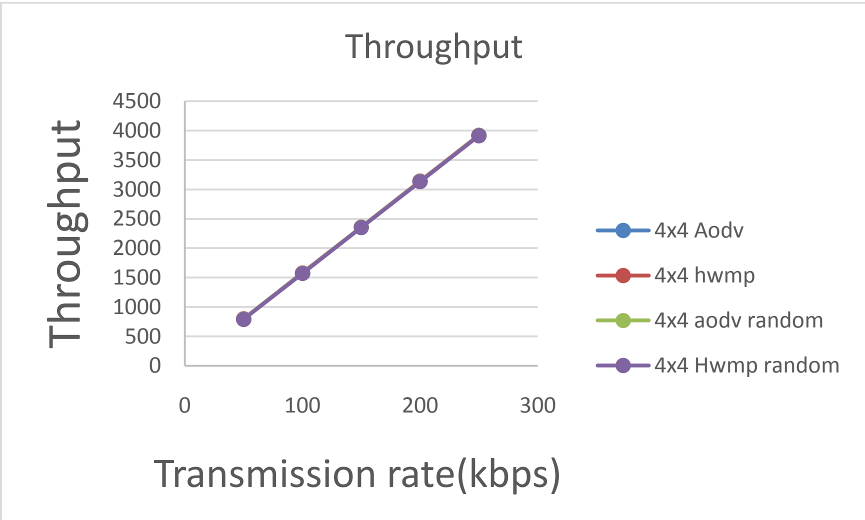

Figure 16. Throughput vs. transmission rate (16 nodes)

Here, all of these protocols perform similar nearly .

6.2.9 When nodes =16, Average End to end delay

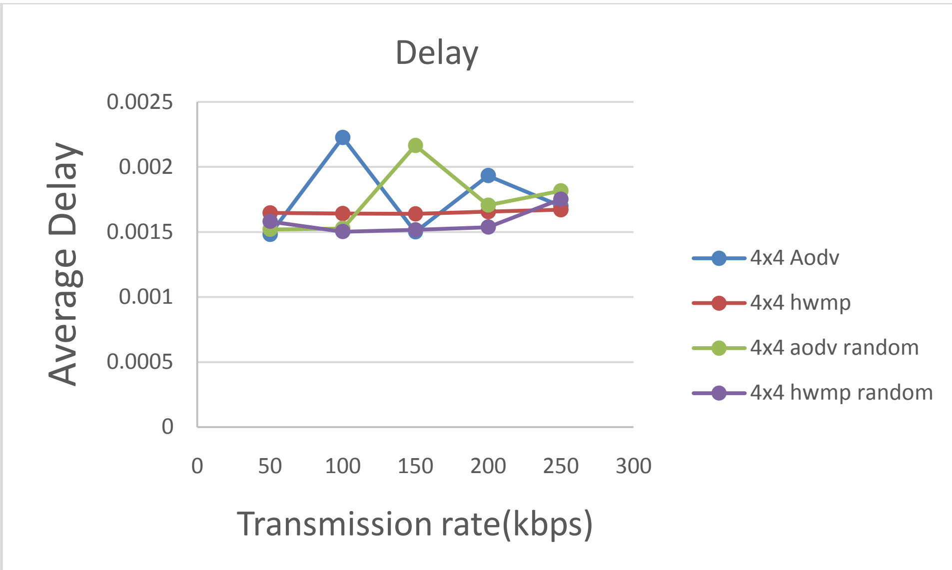

Figure 17. Delay vs. transmission rate (16 nodes)

Here, the best performance is provided by the HWMP and HWMP with random mobility. HWMP works better with the less transmission rate where as with more transmission rate HWMP works better.

6.3 Performance analysis using constant position mobility

6.3.1 Packet delivery fraction (PDF)

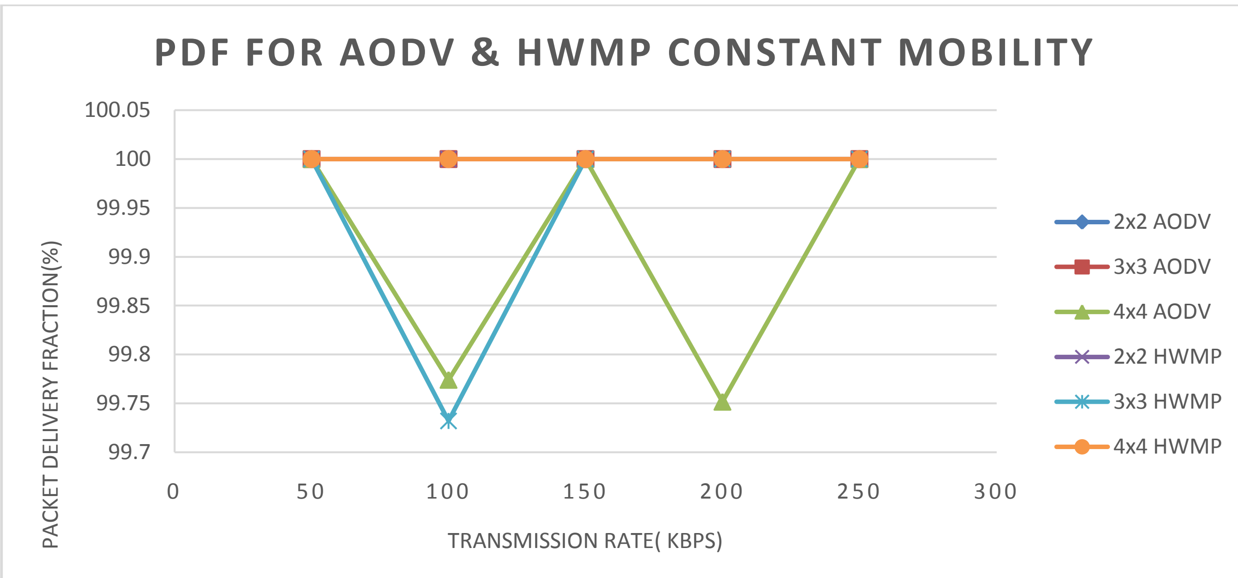

Figure 18. PDF vs. transmission rate (Constant position mobility)

When the mobility is constant, when nodes=4 HWMP and AODV both gives the best performance.
When nodes =9, AODV also gives the better performance and HWMP has the worst performance.
When nodes= 16, HWMP gives better performance than the AODV. AODV's PDF falls and rises with different transmission rates.

6.3.2 Throughput

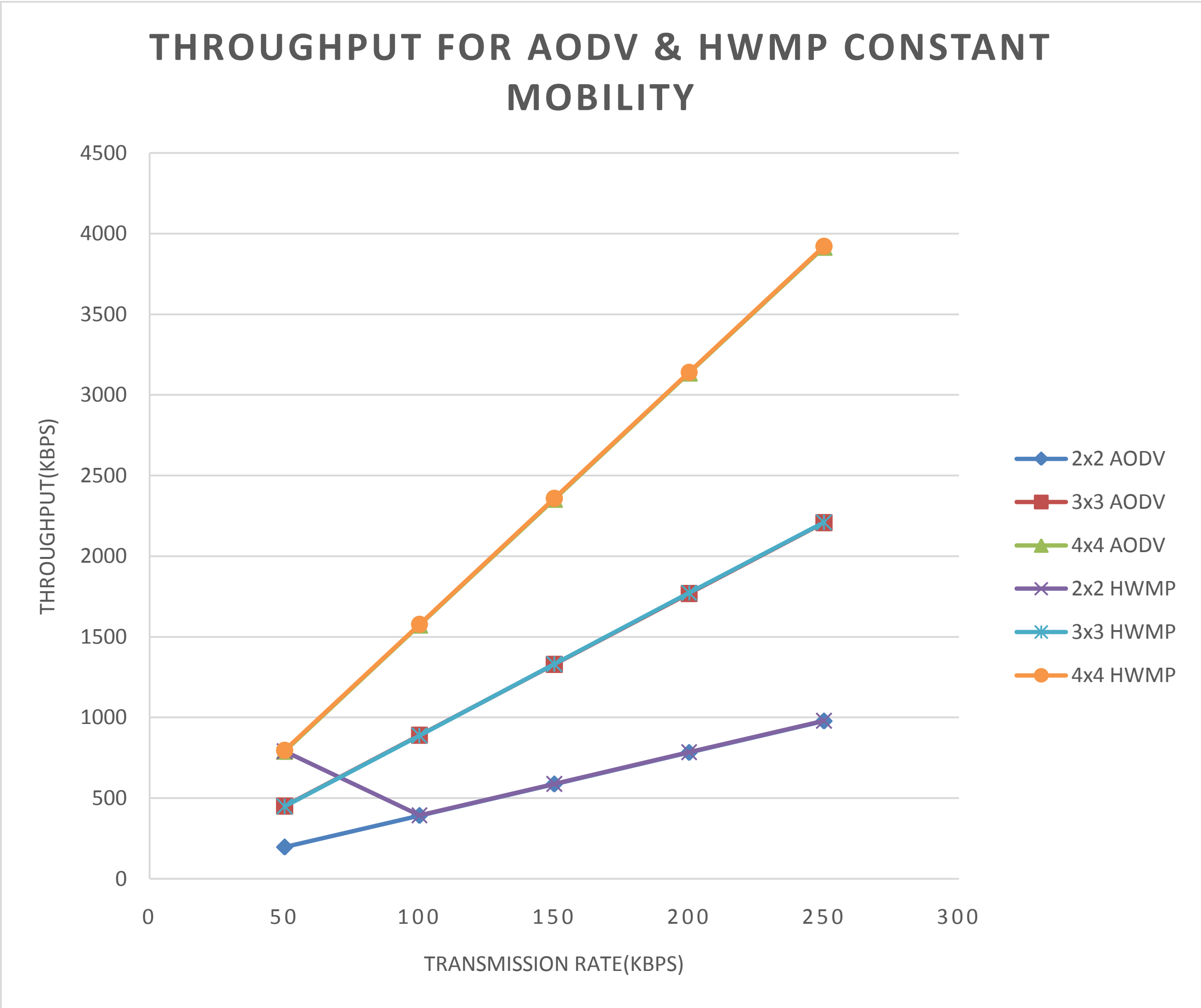

Figure 19. Throughput vs. transmission rate (Constant position mobility)

When the mobility is constant, when nodes=4 HWMP gives the best performance. And AODV gives slightly worst than HWMP.
When nodes =9, AODV and HWMP both has nearly same performance.
When nodes= 16, HWMP and AODV both has nearly same performance also.
So, with the increasing nodes the performance is also rising.

6.3.3 Average End-to End delay

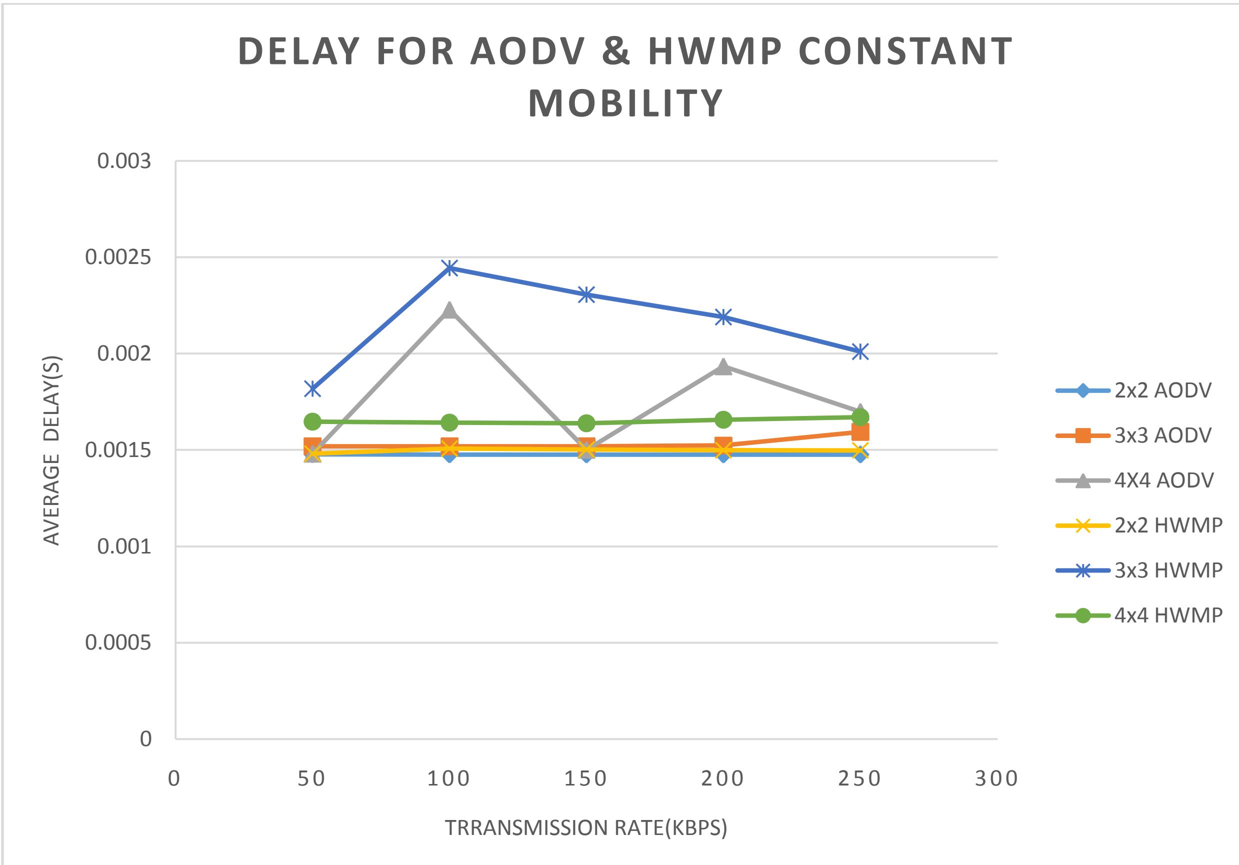

Figure 20. Delay vs. transmission rate (Constant position mobility)

When the mobility is constant, when nodes=4 HWMP gives the best performance. And AODV gives slightly worst than HWMP.
When nodes =9, AODV also gives the better performance and HWMP has the worst performance.
When nodes= 16, HWMP gives better performance than there are many up and downs in AODV's performance.

6.4 Performance analysis using Random waypoint mobility

6.4.1 Packet delivery fraction (PDF)

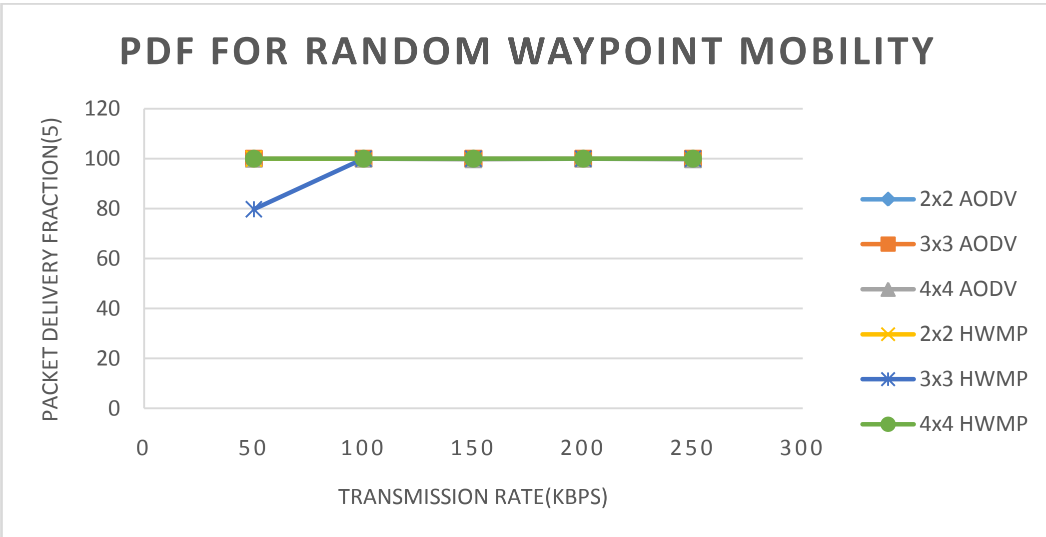

Figure 21. PDF vs. transmission rate (Random waypoint mobility)

All of them perform nearly the same except for the 9 nodes of HWMP.

6.4.2 Throughput

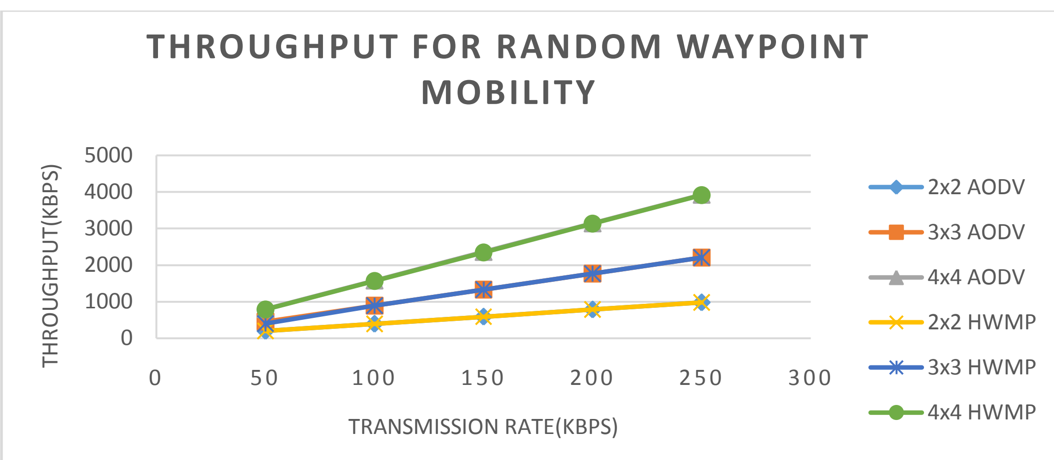

Figure 22. Throughput vs. transmission rate (Random waypoint mobility)

When the mobility is random, when nodes=4 AODV and HWMP both provides the nearly same performance. When nodes =9, they also give the nearly same performance.
When nodes= 16, here they are also nearly same.

6.4.3 Average Delay

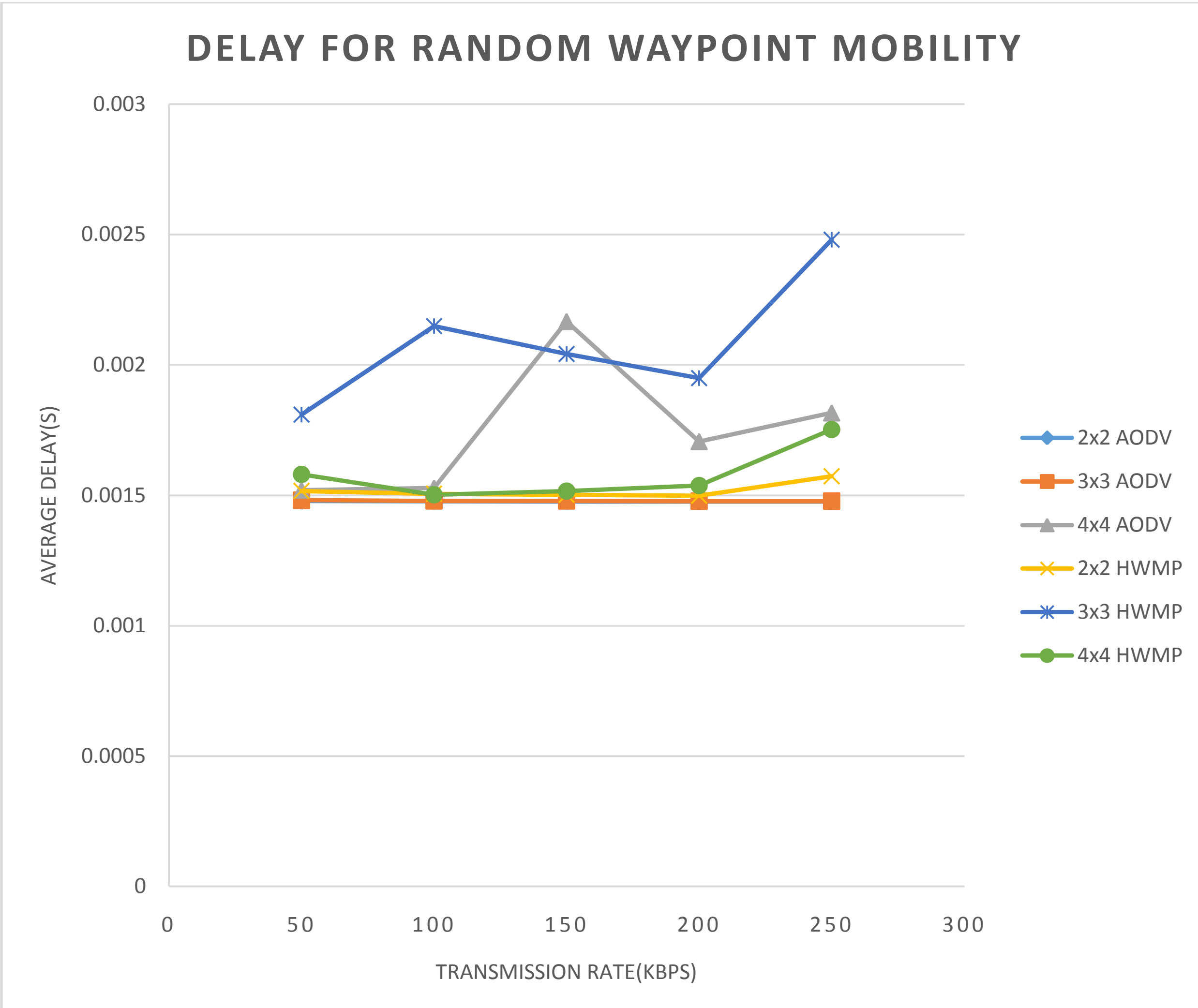

Figure 23. Delay vs. transmission rate (Random waypoint mobility)

When the mobility is random, when nodes=4 AODV gives the best performance. It's slightly better than the HWMP.

When nodes =9, AODV also gives the better performance and HWMP has the worst performance.

When nodes= 16, HWMP gives better performance than the AODV. So HWMP's performance goes better when there are more nodes.

6.5 Overall performance analysis

		Protocols				
Nodes	Parameters	HWMP	HWMP Random Mobility	AODV	AODV Random Mobility	Best Performing Protocol
4	Packet Delivery Fraction (PDF)	100	100	100	100	HWMP,AOD V
	Delay (sec)	0.00150263	0.00150252	0.00147658	0.00147689	AODV
	Throughput (bits/sec)	589.509	588.159	587.403	589.265	HWMP
9	Packet Delivery Fraction (PDF)	100	100	100	100	HWMP,AOD V
	Delay (sec)	0.0023061	0.00204248	0.00151877	0.00147825	AODV Random Mobility
	Throughput (bits/sec)	1331.59	1325.51	1329.67	1328.1	HWMP
16	Packet Delivery Fraction (PDF)	100	100	100	99.7689	HWMP,AOD V
	Delay (sec)	0.00163944	0.00151729	0.0015005	0.00216652	AODV
	Throughput (bits/sec)	2358.44	2350.19	2354.222	2355.7	HWMP
20	Packet Delivery Fraction (PDF)	99.6655	99.7764	88.7907	96.4597	HWMP
	Delay (sec)	0.00323342	0.00279684	0.00264107	0.00881395	AODV
	Throughput (bits/sec)	2938.226	2935.09	2791.16	2919.25	HWMP

Table 3. Performance with increasing nodes

		Protocols				
Transmission rate	Parameters	HWMP	HWMP Random Mobility	AODV	AODV Random Mobility	Best Performing Protocol
50	Packet Delivery Fraction (PDF)	100	100	100	100	HWMP,AODV
	Delay (sec)	0.00148	0.001517	0.001477	0.001478	AODV
	Throughput (bits/sec)	791.902	197.464	196.795	198.685	HWMP
100	Packet Delivery Fraction (PDF)	100	100	100	100	AODV,HWMP
	Delay (sec)	0.001508	0.001507	0.001477	0.001477	AODV
	Throughput (bits/sec)	394.131	392.804	392.099	393.96	HWMP
150	Packet Delivery Fraction (PDF)	100	100	100	100	AODV,HWMP
	Delay (sec)	0.001503	0.001503	0.001477	0.001477	AODV
	Throughput (bits/sec)	589.509	588.159	587.403	589.265	HWMP
200	Packet Delivery Fraction (PDF)	100	100	100	100	AODV,HWMP
	Delay (sec)	0.0015	0.001499	0.001477	0.001477	AODV
	Throughput (bits/sec)	784.883	783.504	782.719	784.575	HWMP
250	Packet Delivery Fraction (PDF)	100	100	100	100	AODV,HWMP
	Delay (sec)	0.001498	0.001573	0.001476	0.001477	AODV
	Throughput (bits/sec)	980.241	978.87	978.032	979.896	HWMP

Table 4. Performance with increasing transfer rate (4 nodes)

		Protocols				
Transmission rate	Parameters	HWMP	HWMP Random Mobility	AODV	AODV Random Mobility	Best Performing Protocol
50	Packet Delivery Fraction (PDF)	100	79.7831	100	100	AODV, HWMP
	Delay (sec)	0.001818	0.001809	0.001519	0.001482	AODV Random Mobility
	Throughput (bits/sec)	449.091	396.21	451.888	449.587	AOVD
100	Packet Delivery Fraction (PDF)	99.7321	100	100	100	HWMP Random Mobility, AODV
	Delay (sec)	0.002444	0.002149	0.001519	0.001479	AODV Random Mobility
	Throughput (bits/sec)	888.922	885.662	890.446	888.727	AODV
150	Packet Delivery Fraction (PDF)	100	100	100	100	AODV, HWMP
	Delay (sec)	0.002306	0.002042	0.001519	0.001478	AODV Random Mobility
	Throughput (bits/sec)	1331.59	1325.51	1329.67	1328.1	HWMP
200	Packet Delivery Fraction (PDF)	100	100	100	100	AODV, HWMP
	Delay (sec)	0.00219	0.00195	0.001523	0.001478	AODV Random mobility
	Throughput (bits/sec)	1773.2	1766.33	1769.41	1767.53	HWMP
250	Packet Delivery Fraction (PDF)	100	100	100	100	AODV,HWMP
	Delay (sec)	0.002012	0.00248	0.001595	0.001478	AODV Random Mobility
	Throughput (bits/sec)	2210.45	2204.34	2208.17	2207.01	HWMP Random Mobility

Table 5: performance with increasing transfer rate (9 nodes)

		Protocols				
Transmission rate	Parameters	HWMP	HWMP Random Mobility	AODV	AODV Random Mobility	Best Performing Protocol
50	Packet Delivery Fraction (PDF)	100	100	100	100	HWMP,AODV
	Delay (sec)	0.001647	0.00158	0.00148	0.00152	AODV
	Throughput (bits/sec)	796.072	787.811	791.902	792.96	HWMP
100	Packet Delivery Fraction (PDF)	100	100	99.7742	100	HWMP,AODV random mobility
	Delay (sec)	0.001643	0.001503	0.002228	0.001528	HWMP
	Throughput (bits/sec)	1577.16	1568.91	1574.24	1573.98	HWMP
150	Packet Delivery Fraction (PDF)	100	100	100	99.7609	HWMP,AODV Random mobility
	Delay (sec)	0.001639	0.001517	0.001501	0.002167	AODV
	Throughput (bits/sec)	2358.44	2350.19	2354.22	2355.7	HWMP
200	Packet Delivery Fraction (PDF)	100	100	99.7518	100	AODV Random mobility, HWMP
	Delay (sec)	0.001657	0.001538	0.001934	0.001707	HWMP
	Throughput (bits/sec)	3139.93	3131.52	3136.8	3136.4	HWMP
250	Packet Delivery Fraction (PDF)	100	100	100	99.7491	HWMP,AODV
250	Delay (sec)	0.001671	0.001753	0.001699	0.001816	HWMP
	Throughput (bits/sec)	3921.26	3912.92	3916.75	3918.25	HWMP

Table 6: performance with increasing transfer rate (16 nodes)

7. Conclusion

In this research we focused on the HWMP routing capabilities over AODV protocol. The implementation of the simulation has been done in NS3 and with the results we have evaluated the performance of both AODV and HWMP, and most of the cases we have seen that the performance of HWMP is slightly better than the AODV.

8. Future Work

We will use HWMP protocol on more complex and complicated scenario. We are also planning to implement our project with more different parameters. In future we will compare HWMP with some other better protocols. HWMP could be an important field to research which would help to improve its performance on a specified wireless mesh network.

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