An Overview of the Multipath Technologies, their Importance and Types

N. A. Jabbar, G. Lencse

***Abstract*— One of the challenges for networks that operate according to traditional protocols is to solve the limitations of the single interface or the single path. Especially in mobile phone networks (4G, 5G, and Wi-Fi) and networks that support smart devices, it is an important question, how to take advantage of network resources or distribute traffic between paths and choose the alternative path in case the current path fails. As a result of the rapid development of applications that depend on the multipath interface, a massive increase in traffic has been occurred. The solutions and algorithms that were studied and discussed gave realistic and distinct solutions to increase throughput and reduce delays, which in turn achieves obtaining high-quality data transmission through multiple paths and thus be able to aggregate resources and reduce blocking in the network in terms of QoS (Quality of Service), QoE (Quality of Experience), which allows faster data transfer compared to cases that use a single path. In this paper, we review a set of technologies that provide multipath services (such as MPT, MPTCP, MMPTCP, AOMDV, and OAOMDV) which have been designed and proven through researchers' experiments to be helpful and promising in solving the above problems. Most of these multipath technologies are in the process of being built, some of which need additions to deal with data packets and others to be sufficient and comprehensive facing with the rapid growth of technology.**

***Index Terms*— MPT, GRE-in-UDP, MPTCP, Multipath Technology.**

I. INTRODUCTION

The growth in the unprecedented increase in demand for the Internet has led to a multiplication of the challenge among Internet service providers to provide a good quality of service. Service providers create and configure all requirements for infrastructure and resources interactively and quickly to deal with new applications and the increasing number of users. One of the main objectives of traffic engineering is to improve the operational network at the level of traffic and resources. That growing growth of Internet and the increase in traffic due to the increased demand for services leads to complexity on the current networks and is ineffective on traditional networks, i.e., the networks that used protocols that have been around since the inception of computer networks [1] [2], that are unable to provide new services and not effective with modern applications. The current transmission offered by the Internet is a single path between the sender and the receiver, which in turn reduces the throughput that can be achieved between them. For example, if we have large files such as video, the transmission of this video will be faster if the applications provide a level of multipath transfer sessions, which will give higher use of the available network resources and thus control traffic during the communication sessions. This property can be achieved for example, by using multipath routing. It gives the host the ability to choose the next node with more than one path to reach the same destination. Transport protocols that support only a single-path suffer from efficiency problems. TCP and UDP do not take advantage of applications that provide multiple interfaces because it uses a single path for transmission and also do not take advantage of the additional bandwidth. All these lead to a reduced throughput. To increase the productivity of network applications, especially in mobile devices that work with multiple interfaces such as (Wi-Fi, 5G, 4G) and cloud computing, multipath transmission should be utilized.

The TCP and UDP protocols cannot adapt to the development in network equipment due to their single path functionality. Additionally, TCP may fail to deal with the errors presented by multipath transmission entirely in the single path. Solving the above problems is one of the reasons that motivate researchers to find solutions by adding capabilities that allow adaptation with multipath protocols. In addition, it increases throughput, improves the quality of experience (QoE) [3], and improves the quality of service (QoS) [4] [5].

The purpose of multipath routing is to take advantage of the primary resources of the network by providing multiple paths between the source and destination. The use of a multipath case provides the ability to collect bandwidth in different paths, and thus the support of the data transfer rate will be higher and better than that of the single path [6]. Multimedia services such as video games and increased accuracy in live broadcasting require significant efforts to manage the exponential growth of these large amounts of traffic on the network. To provide QoE that is acceptable and satisfactory to users, we need high bandwidth, which is one of the challenges in real-time, due to the difficulty of transmission of traffic in mobile nodes.

One of the most critical challenges of real-time video transmission is the multiple paths and low transmission delay. For these reasons, the solutions proposed by researchers to solve the multipath technique are essential to address this challenge. Multiple paths technologies will create multiple routes for each pair of nodes to deliver data packets to the destination. The bandwidth in wireless networks is shared between neighboring nodes due to the proximity of the geographical locations of the nodes. Sometimes there is bandwidth interference, which leads to a decrease in network throughput [7]. Therefore, multipath transmission is considered one of the most promising ways to improve and

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https://doi.org/10.47978/TUS.2022.72.01.004

solve such problems for its ability to speed up high-volume communications such as video and its ability to accumulate bandwidth across multiple paths. In addition to the optimal use of network resources, this leads to improved user experience due to increased reliability and throughput in different environments to deliver data. Recently, support capabilities have been provided for smart and tablet devices and portable devices with multiple wireless communication interfaces, for example, mobile networks. The protocols available for this are TCP or UDP, designed for single-path uses. These protocols are created to establish a connection from one end point to another, for example, once a link is set using the TCP protocol, the IP addresses and Port numbers of source and destination nodes cannot be changed. However, the TCP protocol does not benefit from the possibility of multiple interfaces and mobility in intelligent devices. It thus affects the performance of multiple-use, especially when the network is unstable. One of the most important solutions that have been proposed to solve this problem is MPTCP. It may be used to improve the performance of applications by providing the possibility of multiple paths and changing the path automatically [8]. In next sections various multipath technologies will be studied in detail.

2. MPT (Multi path Technology)

The MPT communication library has been designed and developed at the University of Debrecen [9]. It works at the network level, based on GRE in UDP encapsulation. The performance of MPT in throughput aggregation is explored in both laboratory and output network environments. The measured values of the production network demonstrated that MPT is capable of super-aggregation [10]. The MPT library is a promising solution that provides multiple paths based on tunnels, creating a tunnel between the end nodes. Thus, the virtual tunnel interface traffic is distributed between the physical network interfaces. The presence of a library MPT at the network layer allows applications to use any transport protocol they prefer to communicate. The tunnel's traffic is encapsulated using the GRE in UDP internet-draft [11]. A group of research papers [12] [13] [14] have proven that the library MPT can aggregate the capability of basic physical interfaces.

2.1. The Conceptual MPT-GRE Operating Principe

The purpose of creating MPT technology is the multipath communication technology in the network layer, whose construction depends on GRE-in-UDP encapsulation defined by IETF RFC 8086 (see figure 1) [9].

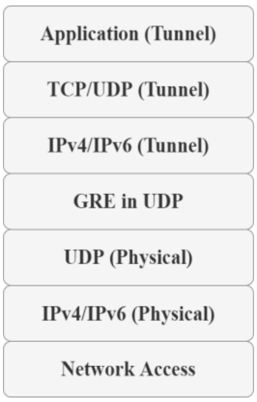

Fig. 1. The structure of GRE in UDP [9]

Multiple paths can be used in the MPT environment. Multipath technology depends on its architecture on GRE-in-UDP technology, where a new logical interface (tunnel) has been added to the traditional layer structure. The work of layers that are above GRE-in-UDP (tunnel) is entirely similar to the traditional environment with UDP except for data coming from the application layer; its transmission will change from a physical interface to a logical interface (tunnel) (see figure 2). The basic principle of MPT works as follows: First, the application uses the logical interface (tunnel) that will be created first on the endpoints to identify the socket, and then MPT-GRE reads the packets arriving at the tunnel interface (IPv4 or IPv6) on the sending host. This packet, before being forwarded through a possible physical path, will be wrapped in a new GRE on the UDP segment. When packets arrive on the receiving host, the header GRE in the UDP segment will be removed before the inline data is forwarded, i.e., the original packets will be delivered. This architecture allows the application to make absolutely no changes to the architecture during an entire communication session. Also, the application uses a single tunnel interface (single logical interface) since Library MPT-GRE uses the UDP protocol during the encapsulation process. The case isn't like MPTCP because it doesn't need to re-send, make sure that packets arrive, and control the flow inside the tunnel interface. [15].

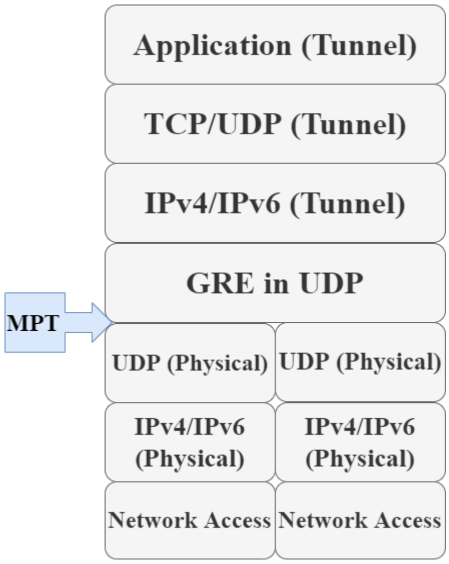

Fig. 2. MPT-GRE conceptual architecture [9]

The PDU architecture for MPT-based communication is depicted in Figure 3. The rightmost three blocks represent the packets from the application layer and are forwarded to the logical interface (tunnel), while the leftmost three blocks for the network interface. MPT-GRE will read the packet arriving at the tunnel interface and assign it the physical interface's IP address. The MPT-GRE library is a dual-stack implementation that should be noted. The layer supports IP version (IPv4, IPv6) and any combination, for example, IPv4 under the tunnel, IPv6 above the tunnel, or vice versa [16].

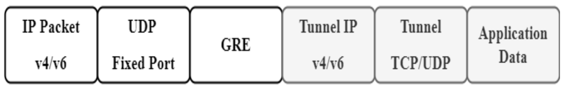

Fig. 3. The PDU structure MPT GRE-in-UDP [12]

2.2. MPT ANDROID

Cases that are applicable and compatible with the mobile environment have been tested. The portability of vertical handover in the text-based terminal environment, and during their experience by calling at the start of a remote SSH session on the tunnel interface through which the two endpoints are connected. The remote endpoint pressed against the local computer tunnel interface while making path session changes using the program control interface. The test proved that the packet was not lost on completion and that session SSH continued uninterrupted. In addition to the above, in another different experiment [17], the effect of vertical handovers on video streams based on (HTTP, RTP) was examined. They studied two scenarios of path state changes. The first is a scheduled shutdown through the help of the control interface, and the second is an unexpected shutdown that usually occurs when a link WAN of the wireless access point is disconnected.

One advantage of the control MPT interface, which encouraged researchers to use it in the mobile environment, is that the packet is not lost when the path or interface is closed. Tunneling between communication endpoints is configured automatically ‹at runtime, additional routes can be configured, and connection settings can be changed [18].

3. GRE TUNNELING

General Routing Encapsulation (GRE) is a protocol used to encapsulate data packets from one routing protocol within packets from another. "Encapsulation" means the packaging of a data packet into another data packet, such as placing a box in another box. GRE is a method of establishing direct peer-to-peer network communication to simplify connections between networks. It works with many network-layer protocols. The benefit of using GRE is to allow the use of protocols that the network cannot support by encapsulating packets inside other packets that use supported protocols, meaning "supported packets of certain protocols feed unsupported packets that they carry over the network." GRE is an excellent way to carry a particular type of data packet inside other data packets that will be traversed by the network by encapsulating unsupported packets, as shown in figure 4 [19].

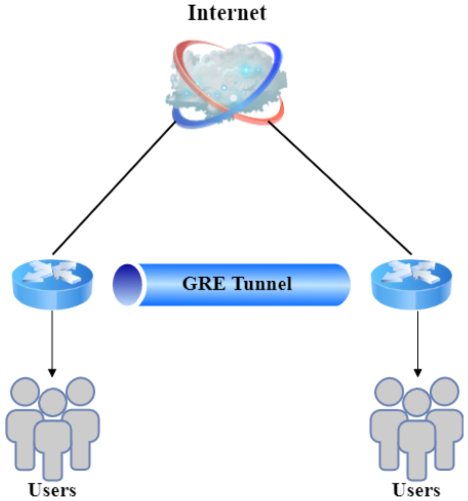

Fig. 4. Encapsulation process of GRE packet

The reason for using GRE is that it supports multiple protocols and certain data packets, especially when setting up VPN networks. However, the corporate address cannot be routed over the Internet, one of the biggest problems that can be faced using tunneling. GRE uses a method of encapsulating the IP with another private address inside another package. This means that it uses another IP header that uses the public discourse [20]. The data packet is encapsulated, as shown in the figure 5.

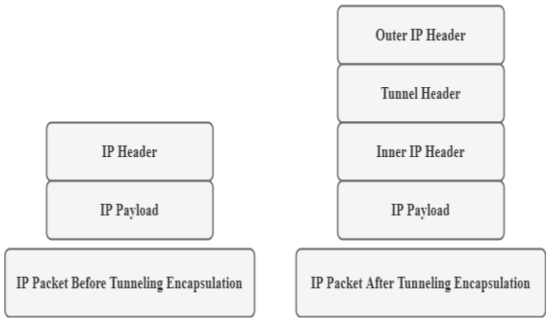

Fig. 5. GRE Packet Format [20]

4. MPTCP (MULTIPATH TRANSMISSION CONTROL PROTOCOL)

Multipath TCP provides the advantage of exploiting and utilizing multiple paths between nodes simultaneously. The application services that Multipath TCP provides are the same as the services that TCP/IP provides, and it gives all the things necessary to build and use multiple flows of TCP for potential paths in a network. Figure 6 shows a comparison between standard TCP and multipath TCP [16].

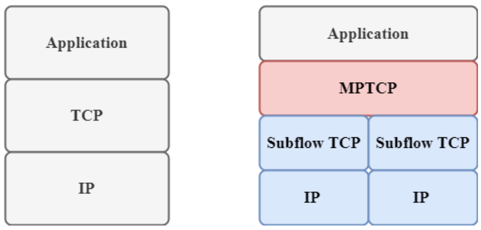

Fig. 6. Comparison between standard TCP and MPTCP [12]

Multipath mechanism in TCP divides the transport layer into two sub-layers. The operations of communication management functions such as establishing communication and rearranging packets are combined in the upper part of the layer. MPTCP assigns two spaces of sequence numbers. Each sub-flow is marked with a sequence space similar to the standard TCP sequence number, to recognize the bytes during a sub flow. The second sequence space is used at the connection level to reorder TCP segments before transferring them to the application layer. [21] [22].

4.1. USING MULTIPATH TCP BY MOBILE ENVIRONMENTS

MPTCP is a multipath mechanism that operates at the transport layer. It creates secondary backup paths for quick handovers allowing capacity pooling for multiple interfaces if the primary route fails. Where the data flow is partitioned by building sub-streams similar to traditional TCP streams between the available network interfaces, the power of these sub-streams is intelligently taken advantage of. Therefore, we do not need to adjust for compatibility because the applications use the standard socket API. The model is implemented in the kernel space, which also allows testing on mobile devices [23].

The capacity to do vertical handovers is derived from MPTCP's operation. When a fault is discovered on any sub flows, it redirects traffic to a still-operational lane while maintaining the MPTCP communication session., boosting the connection's reliability. In [24], the authors have been discussed the problems that arise and the reliability of the handover.

In 2015, a Korean Telecom company presented a solution, which provides it as a commercial solution for Multipath (MPTCP) [25]. The main goal is to collect the bandwidth needed by the available smartphone technologies, which is evidenced by its name dubbed GIGA Path. As mentioned previously, it uses MPTCP and in one all Sub-flow through which data is transmitted and on both interfaces and MPTCP-capable SOCKS proxy server of the service provider. It uses standard TCP to send traffic to the Internet via the provider's high-capacity backbone network. The theoretical bandwidths obtained on LTE-A of 300 Mbps and Wi-Fi of 867 Mbps add to about 1.17 Gbps. Just a few high-end devices support this frequency, and anyway, an evaluated bandwidth of 800 Mbps lags behind the max value; even so, this will modify as newer, more advanced devices hit the market. Energy efficiency is one of the important challenges in mobile environments, which is an essential aspect of the multipath process of TCP, as the measurements aim to analyze the energy consumption [26]. Demonstrate that using multiple interfaces for the same file download uses less energy than using only the 3G interface. Dealing with sub-flows regarding creation, deletion, or any specific processing on them is considered a disadvantage because it requires providing compatibility MPTCP with the socket API. It does not offer a set of tools that enable the user to deal (control) the level of data.

Two different implementation solutions are briefly explained in [18] that provides various levels of control for applications and the user. Authors in [27] provided a basic concept of Socket Intents. The application can obtain additional information about the connection when creating the socket. For example, in the case of streaming, the expected duration and bit rate information can be obtained. In addition to that, additional details on the transfer type can be obtained. For example, they are downloading a large file when bandwidth is critical or multiple downloads of smaller items in an HTTP request when a low RTT is critical. The extension allows the software to specify its transmission requirements, which are then considered when network resources are allocated. SMAPP [28], on the other hand, provides an interface for subscribing to certain MPTCP data plane events that happen in kernel space (e.g., connection creation, sub flow creation, connection end). After the events occur, the app can use the solution's interface to change the behavior of the data plane. Adding and removing sub flows are examples of such changes, but the connection's state can also be queried at any moment to provide a framework for a customized sub flow management method.

4.2. MPTCP with Software-Defined Networking (SDN)

Joining MPTCP and Open-Flow has been proposed in [29]. Open-Flow is Software-Defined Networking (SDN) enabler that can perform network traffic routing, such as determining network topology. SDN can also be used to determine the best route for the headmost sub flow [30]. The ECMP (Equal-cost multi-path routing) can divide a data stream and send it down multiple paths. Moreover, it only ahead flows via the fastest route so sub flows may be forwarded via the same route. One of the advantages of combining MPTCP and Open Flow is the multi-flow method that has been proposed by Sandri et al. [31]. The main reason for suggesting this method is that the data flow is split into common bottlenecks across different communication paths. Multi-flow can achieve fine-grained control of sub flows for Open Flow networks by dividing MPTCP sub flows. Even so, the MPTCP connection's throughput increases only when there are enough disjoined paths.

4.3. Maximum Multipath TCP (MMPTCP)

MMPTCP was introduced by Kheirkhah et al. [32], a multipath transport protocol that helps provide high throughput for large flows and can coexist reasonably with other transport protocols. MMPTCP then effectively assists short flows that have short duration (lifetime) and mostly latency-sensitive [33] in meeting their deadline, it provides low latency and aims to withstand sudden and high bursts during communication that can occur to traffic. Finally, it keeps the changes in the network structure to a minimum. The objectives of MMPTCP are achieved by transmitting data in two parts and two phases. Initially, packets in the network are randomly distributed under a single congestion window by using all available paths. These often contain patterns of traffic flowing. This is a good solution for broadcasts where response time is essential. After a certain amount of data has been transferred, MMPTCP returns to normal Multipath TCP mode, efficiently processing long flows that have long duration (lifetime) via independent congestion windows with each sub stream. Unlike MPTCP, MMPTCP does not have a large tail queue for short flow complete execution, but it does achieve high total network utilization and exceptional throughput for long flows.

5. Multipath Routing Protocols for Mobile ad hoc Networks

5.1. Routing Protocols

According to the adopted protocol in the network, data are transferred between the sending node and the receiving node in Mobile Ad-Hoc Network (MANETs). Routing is the process of determining the path between the source node and the destination node when requesting data transfer. MANET routing protocols differ from conventional wired or wireless networks because the nodes are constrained to limited resources. MANET routing protocols reduce power consumption and extend the network's lifetime, while the traditional network tries to maximize channel performance or reduce node deployment in the network [34]. The routing technique is the key to the success of distributed communications and diverse networks on a large scale. Each algorithm aims to route traffic from source to destination, increase network performance, and reduce costs [35].

Therefore, a static routing mechanism cannot be applied because the network environment changes all the time. Based on that, most current routing mechanisms are prepared to take network dynamics into account. The network might be divided into multiple clusters, and a connection from a source node to destination node is established based on various parameters with different weights, through multiple paths [36]. It is known that in a multiple-hop network environment, the sending node cannot send data directly to the end node. Therefore, intermediate nodes must be used to send their packets [37]. Routing protocol help to build and maintain. Generally, MANET has three routing protocol categories: proactive routing protocols, reactive routing protocols and hybrid routing protocols [38]. Figure 7 illustrates the classification of the MANET protocol according to current constraints, which are subdivided into subcategories [39] [40].

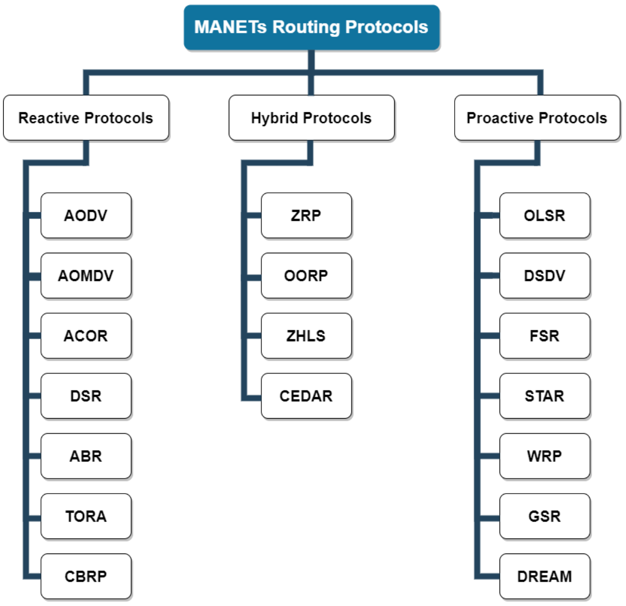

Fig. 7. MANET Routing Protocols

5.2. Proactive Routing

Optimized Link State Routing Protocol (OLSR) is a popular type of proactive routing protocol that depends on the servicing of path tables for end nodes, which decreases the degree of control traffic overhead generated by this type. Because packets are submitted instantly using recognized paths; yet, path tables should be updated regularly; this memory and endpoints are used to sporadically send refresh messages to neighbor nodes, though in the absence of traffic, it results in bandwidth waste. Proactive routing is unsuitable for dynamical networks. Routing tables should be modified with each topological modification, growing control messages and potentially resulting in poor network performance under high load [34].

5.3. Reactive Routing

The packet must be routed through source or vector-oriented routing; reactive protocols such as (AODV or DSR) use the route discovery process to flood the network with route query requests. Source routing employs packet data headers that encompass routing information, which means that endpoints do not require routing tables; however, it has a great load network. Distance vector routing routes packets using the next-hop and destination addresses, which requires a node to store active path information if it is no longer required, or an active delay for the path, avoiding old directions. Overflows are a dependable technique of distributing data across the network [34]. However, it can use bandwidth and produce network overhead. This protocol route packets only when they need to be routed, resulting in long transmission waits. While calculating paths, packets have tiny general control movement and use less memory than proactive choices, increasing the protocol's scalability.

Ad hoc On-Demand Distance Vector Routing Protocol is a well-known example of a reactive routing protocol (AODV). This protocol is designed for ad hoc and wireless networks such as mobile networks. AODV protocol provides on-demand routing to destinations, and both unicast and multicast routing is supported. Only when the original nodes are requested does the AODV protocol create paths between them. Figure 8 (a) and Figure 8 (b) depict AODV phases:

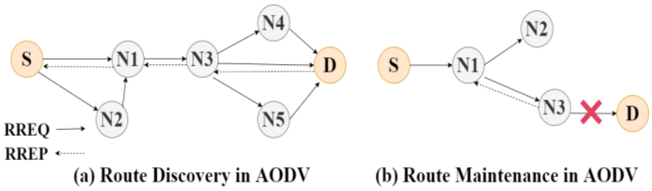

Fig. 8. Route discovery and Route maintenance in AODV

5.4. Hybrid Routing

Hybrid protocols such as Zone Routing Protocol (ZRP) have mixed properties of reactive and proactive routing protocols; and commonly attempt to achieve low-bandwidth traffic overhead in proactive systems while minimizing delays in discovering reactive system methods by maintaining some form of the routing table [34].

5.5. Ad-hoc On-demand Multipath Distance Vector (AOMDV)

This protocol is an extension of the AODV protocol, which is designed to create multiple paths, and as a result of nodes mobility, it computes multiple loop-free and links disjoint paths. The routing paths of each target node contain a list of next or adjacent nodes with the number of corresponding nodes having a similar serial number which in turn helps in following the path the full path of each destination. The maximum number of hops and all paths are saved in the node, which sends the authorized paths to the target node. Each declaration specifies the alternate paths that the node receives to the destination. If a node has fewer hops than the number of hops declared for the target node, then the freedom to choose alternate paths is guaranteed, so the number of declared hops for the same sequence number does not change due to the use of all hops [41]. The next-node list and advertised hop count are revitalized if a route infomercial for a target node with a higher sequence number is gained. Each hop does not promptly refuse iteratively Repeat Requests (RREQs). Each RREQs arriving via a various neighbor of start node defines a hop-disjoint path. The reason that nodes cannot be broadcast RREQs iteratively, thus any two Repeat Requests (RREQs) coming at a medium node via different neighbor nodes of the source could not have passed through the same node. AOMDV is used to search routes that are node-disjoint or link-disjoint.

AOMDV provides the advantage of responding to RREQs through intermediate nodes, while still defining discrete paths. This is the essential feature of AOMDV. But, due to increased flooding during path discovery, AOMDV will have many messages overhead. Since it is a multipath routing protocol, the destination answers multiple RREQs, resulting in a more extended overhead. When the current links between nodes break down, AOMDV searches for alternative paths, and this ability makes it superior to AODV. This process makes it lose a lot of routing expenses significantly when packets are delayed. Still, it is considered more effective and efficient in delivering packets. Also, AOMDV is an on-demand routing protocol that is Better than traditional AODV because it provides excellent statistics on packets and the number of packets dropped [42].

5.6. Optimized AOMDV (OAOMDV)

Numerous multipath routing protocols based on the existing single path routing protocol in ad hoc networks have been proposed to prevent unnecessary frequent route discovery. To help fix the "route cutoff" problem in AOMDV, Optimized AOMDV (OAOMDV) is presented [43]. The suggested technique incorporates a new scheme into AOMDV, and simulation results increase performance [44]. It has updated AOMDV to search a couple of link-disjoint routes beyond the "route cutoff" problem. In reality, if multiple link-disjoint routes between the source and destination with one or more common intermediate nodes, numerous backward roads and two upwards paths should be founded.

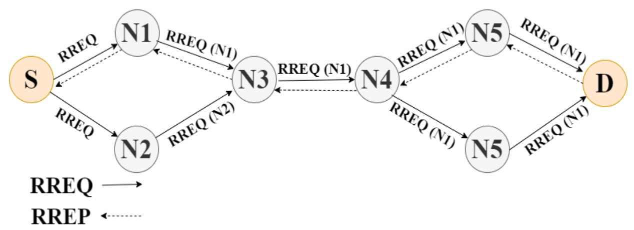

Fig. 9. Build up the reverse-path process

In Figure 9, there are two forward paths (S-N1-N3-N4-N5-D and S-N2-N3-N4-N6-D) and two reverse paths (D-N5-N4-N3-N1-S and D-N6-N4-N3-N2-S). AOMDV, on the other hand, detects only one forward path and two reverse paths (D-N5-N4-N3-N1-S). The different reverse path (D-N6-N4-N3-N2-S) has been severed. To avoid this type of "route cut off," the authors proposed a scheme in which a routing packet RREP ACK (Route Reply Acknowledgement) is added to the forward path and transmitted (S-N2-N3-N4-N6-D). When a packet is received by an intermediate node, a reverse path to the source is established. As a result, the omitted reverse path (D-N6-N4-N3-N2-S) will be realized when packet D arrives at destination D [43].

6. Others Multipath Technologies

6.1. Huawei's GRE Tunnel Bonding Protocol

There is a growing market for alternatives that provide redundancy and load-sharing across wired and cellular connections from a single service provider, allowing a single subscriber to have bonded access to multiple links at the same period. Subscribers used to have separate access to fixed and mobile networks from service providers. Relating these heterogeneous networks together to provide access service to subscribers has become desirable; this service will provide increased access capacity and improved reliability. They concentrate on the use case in which a Digital Subscriber Line (DSL) connection and a Long Term Evolution (LTE) connection are linked. When the traffic volume exceeds the DSL connection's bandwidth, the excess can be offloaded to the LTE connection. A Home Gateway (HG) is a piece of Customer Premises Equipment (CPE) that initiates DSL and LTE connections [45].

6.2. Multiple Interfaces and Provisioning Domains

Multiple provisioning domains (via physical and/or virtual interfaces) can exist on a multihomed node. For example, a node may be concurrently connected to a cabled Ethernet Network, an 802.11 LAN, a 3G cell network, single or more VPN connections, or one or more automatic or manual tunnels. Because modern laptops and smartphones typically have multiple access network interfaces, they are frequently connected to multiple provisioning domains [46]. MIF workgroup of IETF concentrates on the case when nodes have multiple interfaces and are associated with various provisioning domains where choosing between various interfaces is a problem. Since it did not address the distribution of application traffic across different interfaces, some researchers considered it not to be a multipath solution.

6.3. Open Flow Link-Layer Multipath Switching

Multipath open flow link-layer switching OLiMPS is a new approach that employs Link Layer logic, calculating routes as if the nodes were linked by LANs. This approach increases the efficiency and manageability of large networks. Constructed and demonstrated a capable Floodlight-based controller [46]. It was created for the Large Hadron Collider Open Network Environment and used Open Flow [47] technology (LHCONE). In OLiMPS, Data flow mapping optimization in complicated multipath architectures is, and it is a multipath solution that allows for per-flow load distribution.

6.4. The TRILL Protocol of Routing Bridges

Routing Bridges (RBridges) offer efficient pair-wise forwarding without setup, secure propagation even during temporary cycles, and assist for Multipath of both unicast and multicast traffic. These objectives are met through IS-IS routing and traffic encapsulation with a header containing a hop count. Previous IEEE 802.1 customer ridges and IPv4 and IPv6 routers and end nodes are compatible with RBridges. They are as invisible to modern IP routers as bridges are, and they, like routers, terminate the bridge spanning tree protocol. The goal of routing bridges was to combine the benefits of routers and bridges. They employ the TRILL (Transparent Interconnection of Many Links) protocol, allowing multipath forwarding. However, it is intended to be a Local Area Network protocol and is not designed to scale beyond the size of existing bridged LANs" [48].

***Table 1.** A comparison of several multipath technologies*

Paper Authors	*Protocol*	*Technology*	*Functions*	*Layer*	*IP*
B. Almasi et al. [9]	UDP	MPT	MPT technology is the multipath communication technology in the network layer, whose construction depends on GRE-in-UDP encapsulation.	Network	Tunneling
B.Chihani et al. [21]	TCP	MPTCP	Provides the advantage of exploiting and utilizing multiple paths between nodes simultaneously; it divides the transport layer into two sub-layers.	Transport	Routing
M.Kheirkhah et al. [32]	TCP	MMPTCP	Helps provide high throughput for large flows and can coexist reasonably with other transport protocols.	Transport	Routing
B. Rekha et al. [42]	AODV	AOMDV	Computes multiple loop-free and links disjoint paths.	Network	Routing
Y. YuHua et al. [43]	AODV	OAOMDV	To help fix the "route cutoff" problem in AOMDV.	Network	Routing
Yang Yu et al. [49]	STP	ODLBMP	uses multiple paths to deliver traffic between two communication points and dynamically observes and adapts the traffic load assigned to each route.	Link	Routing
H. Newman et al. [47]	OSCARS	OLiMPS	Employs Link Layer logic, calculating routes as if the nodes were linked by LANs.	Link	Routing

6.5. Optimized Dynamic Load-Balancing Multipath (ODLBMP)

ODLBMP was proposed by [49] for DCE (Data Center Ethernet) due to bandwidth misuse and lack of multipath acquisition in the Spanning Tree Protocol (STP). It is an ideal solution for multipath in a DCE by using all available connectors and ports to segment the traffic of all paths continuously. In ODLBMP, traffic loads are constantly monitored for the various available routes to avoid overuse of the path. To ensure that all streams are delivered in the order in ODLBMP, the routing of each stream is monitored. In ODLBMP, the streams are finely tagged for flexibility in route selection and traffic segmentation; ODLBMP has the advantage of achieving better multi-path load balancing.

7. Discussion and Future Directions

The proposed protocols for solving multipath technologies depend on different layers, each with various benefits and characteristics. See table 1 summarizes the work of the previously explained protocols. There are a number of challenges and open problems that need to be addressed.

In mobile environment, the participating nodes are mostly resource-constrained. Although routing through multipath increases the system efficiency, but due to the nature of the participating nodes, the energy efficiently has to be taken into consideration while developing multi path solutions. Also one of the challenges and open problems of the MPT system is creating algorithms that deal with per flow-based mapping and congestion control.

8. Conclusion

This paper provides a comprehensive overview of multipath protocols including various types of protocols type such as MPTCP, MPT GRE-in-UDP, and AOMDV. Given the rapid development in traffic density and the network's ability to deal with this problem, in addition to the possibility of benefiting from better exploitation of network resources, multipath is a promising solution. MPT technology and other technologies such as MPTCP are practical approaches optimizing network resources. MPT is based on GRE-in-UDP technology, through which it provides tunneling through multiple paths, which makes it different from other technologies such as MPTCP and Huawei's GRE Tunnel Bonding. Finally, through our study, we concluded that it can be clearly observed from many results that multipath technique mechanisms enhanced the performance of the networks. However, some problems such as energy efficiency and traffic congestion remain open and more investigation in these fields are required.

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