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ADAPTING IPV6 AND 6LOWPAN OVER WIFI-BASED AODV MANETS FOR IOT APPLICATIONS

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Abstract
Ad-hoc On-demand Distance Vector (AODV) is a routing protocol for Mobile Ad-hoc Networks (MANETs) to facilitate communication between wireless nodes in a dynamic, infrastructure-less environment. It was initially designed to use IPv4, however, with the evolution and wide adoption of IPv6 as the next generation network protocol, especially for the Internet of Things (IoT) envoirnment, there is a need to adapt AODV for use in IPv6 MANETs and investigate its suitability for deployment of IoT nodes under mobility, where several mobile sensor nodes may need to gather data and collaborate dynamically. Additionally, AODV can also be used to facilitate multi-hop communication between vehicles on the road, enabling applications such as cooperative collision avoidance, traffic management, and infotainment services. The evaluation of IPv6-based AODV needs an extensive simulation study in a network simulator, such as NS-3. We have, therefore, extended NS-3 by implementing and testing a model of AODV in NS-3 that operates using IPv6 protocol; currently, NS-3 has an IPv4-based AODV module. The adaptation of AODV to IPv6 requires mapping its complete functionality from IPv4 to IPv6, including node addressing, replacement of broadcast with multicast, features specific to Internet Control Message Protocol (ICMPv6) such as duplicate address detection (DAD), and address resolution using neighbor solicitation and neighbor advertisement messages, instead of the traditional Address Resolution Protocol (ARP). We designed our experiments to extensively test our model for small to large-scale deployment of nodes, low mobility, and small-size frequent messages, to model the IoT environment. Our simulation study involved verifying the correct functionality of AODV with IPv6, along with comparing the protocol performance of AODV in IPv4 and IPv6-based WiFi MANETs. Our results indicate that AODV operation with IPv6 does not significantly degrade the

network performance in comparison with IPv4; however, an increase in control overhead was observed due to large IPv6 headers. We, therefore, extended our experiments to compress IPv6 headers by incorporating 6LoWPAN as a shim layer above the WiFi MAC. 6LoWPAN has originally been designed for IEEE 802.15.4 to carry large IPv6 packets inside small frames of Low-Rate Wireless PAN (LR-WPAN) technology. By employing header compression of 6LoWPAN, we were able to reduce the control overhead of IPv6-based AODV. As a result of this work, we have extended NS-3 functionality by implementing an additional module of AODV protocol based on IPv6, tested its correct functionality in WiFi-based MANETs, and compared the network performance of IPv4-based AODV with that of AODV with IPv6 and 6LoWPAN for possible application in IoT environment.

INTRODUCTION

AODV [1] is a reactive, on-demand routing protocol designed for MANETs. Unlike proactive protocols that maintain a continuously updated routing table for all possible destinations in the network, AODV establishes routes only when they are needed [2-6]. This on-demand nature makes AODV more bandwidth-efficient and adaptable to dynamic network conditions. AODV has found applications in various scenarios, including mobile and vehicular ad hoc networks, where nodes can join and leave the network frequently [7-11].

Its on-demand nature and loop avoidance mechanisms contribute to its suitability for dynamic and resource-constrained environments.

IoT Networks [12] require the use of IPv6 [13] because of its huge IP address space. In addition to providing sufficient addresses, IPv6 offers several benefits for IoT devices, including Stateless Address Auto-Configuration, Neighbor Discovery, Router / Subnet Discovery, and much reduced protocol processing. It also provides faster processing at routers due to a lack of checksum and fragmentation needs. IPv6 supports three types of addresses, which are Unicast Address, Multicast Address, and Anycast Address.

In order to support routing of data in IPv6 based IoT networks, Routing Protocol for Low-Power and Lossy Networks (RPL) [14] has been standardized by IETF, with a focus on achieving energy efficiency and reliability in networks with low power devices. However, RPL is not primarily meant for nodes with frequent mobility needs, like in MANETs [15]; it only provides limited mobility support. RPL is optimized for relatively stable topologies and may not handle mobility scenarios as efficiently as AODV. RPL is designed primarily as a proactive protocol; maintains routing information and keeps updating the routes periodically, even when they are not needed. This approach consumes memory and bandwidth for IoT devices. Also, the overhead associated with periodic control messages and route maintenance impacts performance in a resource constrained environment. RPL mainly utilizes unicast communication with limited support for multicast, which is a drawback for applications relying on multicast packet delivery. Moreover, RPL might not provide effective mechanisms for route optimization based on mobility patterns or location updates. Therefore, RPL may not be the most suitable choice for highly mobile IoT scenarios [16-22].

ICMPv6 [23] is essential for proper functioning and maintenance of IPv6 networks. Neighbor discovery uses ICMPv6 messages and multicast addresses to discover and maintain information about neighboring devices. It replaces and enhances the functionality that was performed by ARP [24] (Address Resolution Protocol) and ICMPv4 [25]. The major functions include, router discovery, prefix discovery, address auto-configuration, duplicate address detection, address resolution, neighbor unreachability detection, packet redirection and parameter discovery [26-34]. ICMPv6 defines a number of message types to exchange information between IPv6 nodes, which are used in various ways to provide above mentioned services. These messages include neighbor solicitation (NS), neighbor advertisement (NA), router solicitation (RS), router advertisement (RA) and redirect message (Redirect).

While ICMPv6 encompasses a broader set of messages for error reporting and other purposes, Neighbor discovery is a subset of ICMPv6 that specifically deals with neighbor and router related tasks in an IPv6 network [35-44].

6LoWPAN [45] is a protocol adaptation layer designed for IoT devices with constrained resources. It enables the use of IPv6 over low power wireless networks, offering efficient addressing in resource constrained devices. 6LoWPAN was basically designed for IEEE 802.15.4 [46] protocol which targets low-power personal area network. Since IPv6 allows packet size much larger than the largest IEEE 802.15.4 frame, an adaptation layer was defined; MTU for IPv6 packets is 1280 octets, and consequently, a full size IPv6 packet cannot be carried inside a small IEEE 802.15.4 frame. The adaptation layer must be provided to comply with the IPv6 requirements of a minimum MTU. 6LoWPAN provides three major functions, (a) stateless and shared context compression of IPv6 packet headers, (b) fragmentation and re-assembly of IPv6 packets for transmission over IEEE 802.15.4 networks, and (3) forwarding of IPv6 packets at link layer. 6LoWPAN header compression does not keep any flow state; instead, it relies on information pertaining to the entire link [47-52]. Many of the IPv6 header fields are expected to be common in 6LoWPAN networks; e.g., version is IPv6, both IPv6 source and destination addresses could likely be link local, packet length can be inferred from link layer headers, both the traffic class and flow label are zero, the next header is either UDP [53], ICMPv6 or TCP [54]. The only field which requires inline 8 bits is the Hop Limit. Based on these, the common IPv6 Header can best be compressed to 2 bytes (1 byte for header compression encoding and 1 byte for hop limit) instead of the 40 bytes. In addition, 6LoWPAN has provisions for compressing the next header, which could be either of the transport layers, TCP or UDP. In this context, 6LoWPAN has the ability to compress UDP headers. 6LoWPAN also includes optimizations for Neighbor Discovery to conserve power in resource-constrained devices and networks [55-62].

Our proposed system can be implemented in Wifi-based MANETs, where multi-hop connectivity at network layer is provided by the use of a MANET routing protocol, such as AODV, OLSR [63], DSDV [64], etc. MANETs, characterized by their infrastructure-less, self-organized, and self-configurable nature, comprise wireless mobile nodes capable of arbitrary movement, enabling functionality in dynamically changing topologies. This flexibility makes MANETs suitable for various applications, particularly in scenarios where traditional infrastructure is impractical or unavailable. Despite the manifold advantages of MANETs, a notable gap exists in current simulation environments such as NS-3 [65], which lacks native support for MANET routing protocols in the context of IPv6-based AdHoc networks. To bridge this gap, adaptations of existing MANET routing protocols designed for IPv4 networks are imperative. Specifically, modifications are required to ensure seamless integration and optimal performance within the IPv6 framework. The transition to IPv6 is crucial for addressing the limitations of IPv4, including but not limited to the exhaustion of address space and the growing demand for a more robust and scalable network infrastructure. Consequently, our proposed system not only introduces a novel approach to MANETs in the context of Wifi-based networks but also addresses a critical need for the adaptation and implementation of MANET routing protocols in the evolving landscape of IPv6 based adhoc networks within the NS-3 simulation environment [66-78].

The specific objectives of this work are, to:

- Investigate the adaptation of AODV protocol to use IPv6 instead of IPv4, along with the possible integration of 6LoWPAN over IEEE 802.11 [79] wireless nodes.
- Implement our proposed system in network simulator NS-3 by developing an NS-3 module for AODV using IPv6 addressing and integrating it with 6LoWPAN module.
- Test the system operation in NS-3, for correct routing in WiFi MANET using our IPv6 based AODV protocol, while performing header compression for IPv6 and UDP protocols by use of 6LoWPAN.
- Compute the network performance of our proposed system by designing NS-3 simulations with mobile nodes in various configurations, (i) AODV with IPv4, (ii) AODV with IPv6, and (iii) AODV with IPv6 and 6LoWPAN compression; and then compare the results to determine if our proposed IPv6 based AODV combined with 6LoWPAN compression can

provide efficient routing solution for mobile nodes operating in adhoc mode.

2. Methodology

AODV was originally designed and has extensively been tested for IPv4 networks. It can be adapted to work in IPv6 environment with appropriate modifications. IPv6 introduces several changes compared to IPv4, including a different addressing mechanism, header format, and neighbor discovery process. To make AODV work with IPv6, we need to consider these differences and adapt the protocol to ensure that AODV can perform efficient routing in IPv6 networks, employing various protocol mechanisms including route discovery, routing table updates, packet forwarding, route maintenance, just as it does with IPv4. The following aspects need to be considered:

2.1. IPv6 Addressing and Protocol Processing

IPv6 has a different address format from IPv4, and IPv6 nodes employ multiple addresses, including primarily the link-local, unique-local and global-unicast. Link-locals are configured automatically on each IPv6 enabled interface and allow packet delivery within a single network segment, while unique-locals cannot be routed globally. Nodes in an adhoc network needing no connection to the Internet can be configured simply with link-local addresses to provide necessary node connectivity. Moreover, the design of IPv6 protocol promises lower processing overhead compared to IPv4. IPv6 features a more streamlined fixed size header, and removal of certain elements, like checksum and options, which contribute to efficient processing. AODV for IPv6 needs to consider these differences and is expected to enhance the efficiency of the overall routing process.

2.2. Address Configuration

IPv6 supports multiple methods for address configuration, including stateless auto-configuration and Dynamic Host Configuration Protocol (DHCPv6) [80]. AODV for IPv6 takes into consideration the address configuration methods when setting up the adhoc network and determining route information. These considerations are crucial for ensuring that AODV seamlessly interfaces with diverse IPv6 address assignment mechanisms, providing robust routing solutions in IPv6 networks with varied address configuration scenarios.

2.3. Packet Format

AODV packets would need to be modified to work with IPv6, which includes adjusting the packet headers and message formats to include IPv6 addresses and relevant protocol fields. The primary adaptation involves updating the address carrying fields to accommodate large size addresses. AODV packet headers, as those for Route Request (RREQ) and Route Reply (RREP), must be revised to reflect IPv6 addressing and header structures. Additionally, considerations for the absence of a header checksum in IPv6 and the utilization of Neighbor Discovery for address resolution need to be incorporated into the modified AODV packet format.

2.4. Handling Broadcast

IPv4 makes use of network level broadcast to disseminate packets to all hosts on local network segment. IPv6 has no equivalent of broadcast address; rather relies on multicast addresses to achieve similar functionality, more efficiently. A multicast address is used to send traffic to a group of hosts rather than all hosts on a network segment. AODV for IPv6 needs to map between broadcast and multicast functionality to adapt its operation to absence of a broadcast facility. AODV with IPv4 utilizes broadcast for route discovery, allowing a node to inquire about routes to destinations from all neighbors. Since IPv6 lacks broadcast addresses, AODV for IPv6 must employ multicast packet delivery. All nodes multicast address and all routers multicast address in IPv6 can serve the similar purpose, allowing AODV to efficiently disseminate route discovery packets to all relevant nodes in the adhoc network, rather than broadcasting on local network segment. While AODV module in NS-3 does not handle multicast, this transition from broadcast to multicast is a crucial adaptation, maintaining the efficiency of route discovery while aligning with the IPv6 multicast-based communication paradigm. It ensures that AODV in IPv6 achieves its routing objectives effectively in the absence of the traditional broadcast.

2.5. Neighbor Discovery

In IPv6, Neighbor Discovery Protocol (NDP) replaces ARP for address resolution and neighbor discovery. AODV would need to adapt to work with NDP, using Neighbor Solicitation (NS) and Neighbor Advertisement (NA) messages, to gather and maintain neighbor information.

2.6. Duplicate Address Detection

In IPv6, DAD [81] is part of IPv6 address auto-configuration process and determines if an IPv6 address is already in use on a network segment before assigning that address to a device. The variation includes strong DAD and weak DAD, which differ in how they perform the address conflict detection process, and the choice between them depends on the specific use case and network configuration.

- Strong DAD is more reliable and recommended for most network configurations as it ensures no address conflicts. However, it may introduce slight delay during address assignment, or cause problem in case of mobility induced network partitioning.
- Weak DAD is suitable in scenarios where address conflicts are unlikely, as in well-managed networks with carefully coordinated address assignment. It is faster but still carries risk of address conflicts.

In the context of IPv6, address uniqueness through DAD is checked within a single network segment or link. AdHoc network, being multi-hop, makes DAD more challenging compared to traditional single-hop networks, as it requires traversing multiple hops or routers to reach the destination. As such, DAD in AODV needs adjustment to work efficiently in scenarios where address uniqueness is to be verified in multi-hop topology.

2.7. Address Resolution

In IPv6, the process of address resolution is handled by the Neighbor Discovery Protocol, which is part of the ICMPv6 suite. This process is similar to the ARP used in IPv4. The main goal of address resolution in IPv6 is to map a target IPv6 address to its corresponding link-layer (MAC) address. This Neighbor Discovery process in IPv6 is efficient and helps nodes on the same link discover each other's link-layer addresses dynamically. It is a key component for the proper functioning of IPv6 networks, and it replaces the ARP process used in IPv4.

2.8. Route Discovery

AODV's route discovery process remains somewhat similar in IPv6. In IPv4 based AODV, when a node needs to send data to a destination for which it doesn't have a route, it broadcasts a RREQ message. However, use of IPv6 would mandate handling of multicast delivery, and also require adjusting the format of RREQ messages and its options to accommodate IPv6 addresses.

2.9. Route Maintenance

The process of maintaining routes in AODV would also need to consider the differences in IPv6, such as larger address space and different header formats. When a route becomes stale or broken, AODV would have to send an appropriate Route Error (RERR) message to inform other nodes about the change.

2.10. Hop-by-Hop Forwarding

AODV, like many routing protocols, operates on a hop-by-hop basis. In IPv6, this would involve forwarding packets based on the destination IPv6 address and the routing information maintained by the protocol.

2.11. Route Table Updates

The routing table in AODV for IPv6 would store IPv6 addresses and associated routing information, such as sequence numbers, hop counts, and next-hop addresses. The maintenance of these tables would be adapted to handle IPv6 specific data.

2.12. 6LoWPAN Compression

6LoWPAN lays down header compression mechanisms to minimize the size of IPv6 and UDP headers. In this proposal, we intend using 6LoWPAN stateless header compression feature in wireless LAN environment. Fragmentation of IPv6 packets will not be needed for MAC layer, as the size of WiFi frame is large enough to carry an IPv6 packet. Also, link layer forwarding is not required, as we intend to use network layer AODV routing. By reducing the header sizes, we expect to see a decrease in control overhead at network and transport layers, associated with data and control packets. However, the AODV control packets will not be compressed as we currently do not intend modifying the AODV route request, route reply and route error messages. This compression will contribute to the overall reduction in control overhead in AODV routing with IPv6, and thus increase transmission efficiency.

3. Simulation Setup

In this work, we have used NS-3 discrete-event network simulator (version 3.35) to implement our proposed model of IPv6 based AODV routing protocol. We designed and conducted various simulations in different network scenarios to analyze the behavior of our model, and to measure the network. NS-3 provides several modules to facilitate design and conduct of network simulations, from which we considered the following:

- Node and Device models for creation of nodes allocating network devices
- Internet Stack model to install IPv6 and related Internet protocols on nodes
- WiFi module to use IEEE 802.11 wireless network in adhoc mode, by setting up WiFi Remote Station Managers
- Mobility model to randomly place nodes at specific positions within a defined area, and add mobility with certain speed and pause time
- UDP module for UDP client-server application to model transmission of packets across multiple client-server pairs
- 6LoWPAN module to compress IPV6 packet headers to reduce control overhead
- Energy model to investigate energy consumption on each node

3.1. Simulation Scenarios

We generated simulation scenarios with 10, 20, 30, 40 and 50 nodes. Simulation time for each node scenario was set to be 1000 seconds. There were five source-destination pairs, which transmitted 20 bytes packets at the rate of one packet per second, for each pair. The simulation area was 500*500 meters, and node speed was kept constant at 100 meter per second, with no pause time. Each node started with 1000 joules of energy in order to calculate the overall energy consumed per byte of data. Simulations were configured with the following scenarios for evaluation:

1. AODV with IPv4 protocol
2. AODV routing with IPv6 (without 6LoWPAN compression)
3. AODV routing with IPv6 and 6LoWPAN compression

3.2. Performance Metrics

3.2.1. Throughput

Throughput indicates how much data rate the application was able to achieve; given as packet size divided by its delay. It is computed for each packet and then averaged over all packets.

3.2.2. End-to-End Delay

Time taken to deliver a packet from source to destination; delay for each packet received correctly is determined and then average is computed over all such packets.

3.2.3. Energy Consumption

Energy consumption per kilobyte of data; estimation of energy consumed for all send/receive operations includes energy consumption for both broadcast and point-to-point transmissions. The protocol with lower energy consumption has higher energy efficiency.

3.2.4. Control Overhead

When data is sent, communication protocol generates overhead in the form of control packets and protocol headers; excessive control overhead results in lower protocol efficiency. Control overhead is computed for all transmissions and then averaged.

3.2.5. Transmission Efficiency

The ratio of data bytes delivered to destination per unit of control byte transmitted for protocol operation. The protocol that transports more data bytes for each control byte transmitted has higher transmission efficiency.

3.2.6. Packet Delivery Ratio

The ratio of packets generated by the source and those actually delivered to destination.

4. Results

4.1. Network Performance

The network performance of AODV was measured for all simulation scenarios and node configurations, as mentioned in Section 3.1. The evaluation results for performance parameters are presented in the following graphs.

4.1.1. Throughput

Throughput in our scenarios also got in favor of IPv6 due to its larger address space, streamlined header structure, and improved network efficiency. The elimination of broadcast communication and enhanced security features contribute to a more optimized data transfer process, resulting in improved throughput in IPv6 networks.

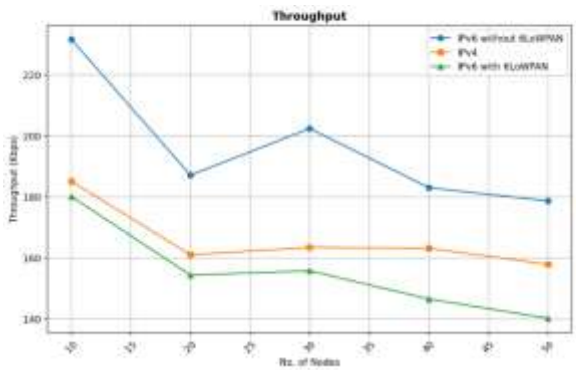

Figure 1. Throughput (Kbps)

4.1.2. End-to-End Delay

Our results determined that AODV with IPv6 incurs lower delay compared to AODV with IPv4. This is due to the simple and streamlined header structure for IPv6, which facilitates faster processing at routers, leading to quicker transmission times. Interestingly, the end to end delay is relatively higher for sparse networks, and gets reduced as nodes in the network are increased. This is because increasing the number of nodes results in higher level of multi-hop connectivity within the network, thus providing more number of valid paths between any source-destination pair. Also, it provides mobile nodes greater opportunity for discovering alternate paths in case of some local path disconnect due to node mobility. As the number of nodes gradually increases, the delay would increase due to higher collision rates.

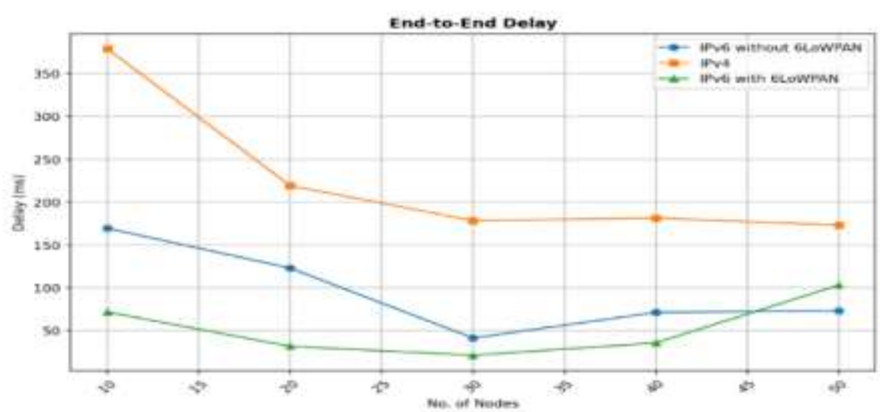

Figure 2. End-to-End Delay (ms)

4.1.3. Energy Consumption

AODV with IPv6 and 6LoWPAN exhibits higher energy efficiency compared to AODV with IPv4. The streamlined design of IPv6 reduces processing overhead, leading to lower energy consumption in network devices. These factors make IPv6 a preferred choice for sustainable and energy conscious network implementations.

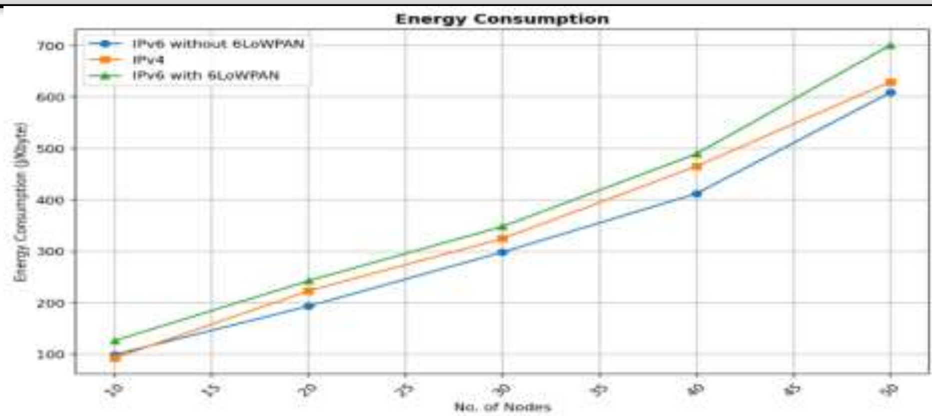

Figure 3. Energy Consumption (Kbytes)

4.1.4. Control Overhead

As expected, AODV has higher control overhead for IPv6 compared to IPv4. The impact is more pronounced in dense networks compared to when number of nodes is small. This is the combined effect of different types of transmissions in the network, for data as well as control information belonging to AODV or ICMPv6. AODV packets for route request, route reply and route error are encapsulated in IPv6 headers. Also, ICMPv6 packets (NS, NA, RS, RA), which flow across an IPv6 network to discover information about the network and neighboring devices, also have the IPv6 header; in case of AODV with IPv4, the functionality related to address resolution is performed at link layer, and does not require a network layer header. IPv6 operation, therefore, suffers from higher number of control packets, and also higher overhead per control packet (four times larger IPv6 address, 16 bytes compared to 4 bytes for IPv4). However, the use of 6LoWPAN results in slight reduction due to header compression. If we also adapt the AODV protocol to include compression for route request, route reply and route error message headers, we can achieve a lower overhead.

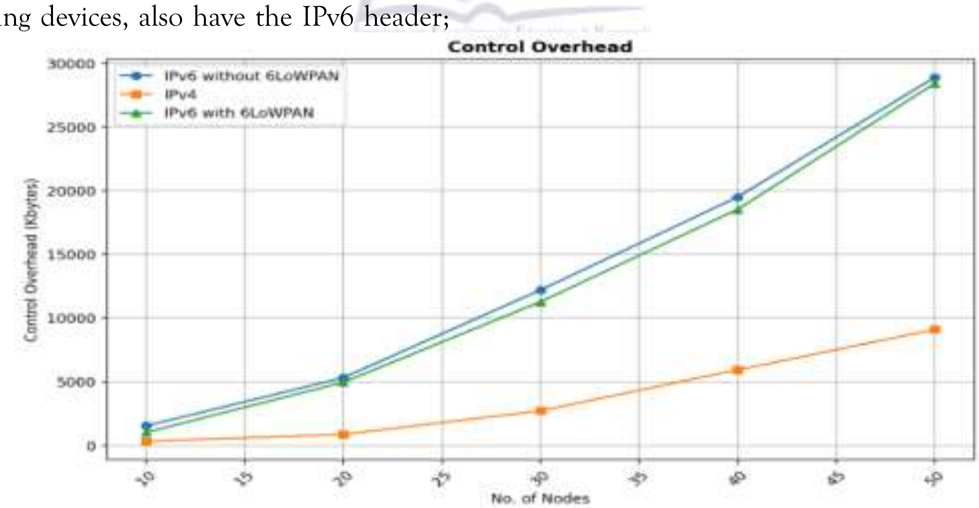

Figure 4. Control Overhead (Kbytes)

4.1.5. Transmission Efficiency

Transmission efficiency is directly related to control overhead. As control overhead is higher for AODV using IPv6, the transmission efficiency of routing is reduced when IPv6 addressing is used. This effect is more pronounced in networks where the number of nodes is large.

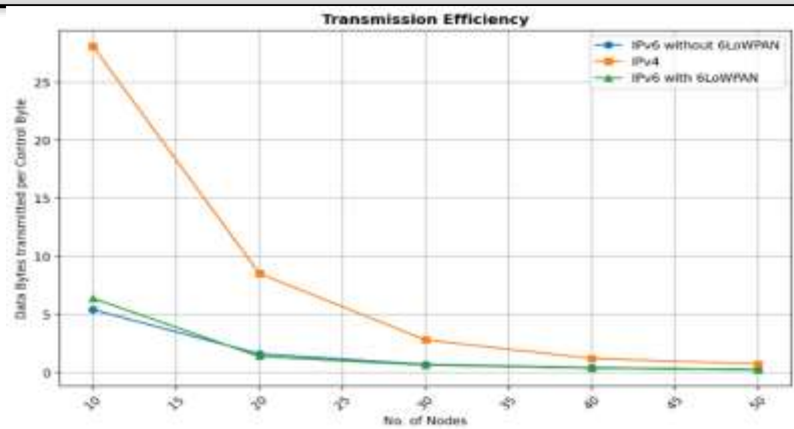

Figure 5. Transmission Efficiency

4.1.6. Packet Delivery Ratio

The results indicate that packet delivery ratio of packets using IPv6 addresses is slightly better than those using IPv4 addresses. IPv6 may exhibit better packet delivery ratio due to its streamlined, fixed size header structure, and lower processing needs due to lack of checksum and fragmentation built-in support for stateless address auto-configuration and elimination of broadcast communication.

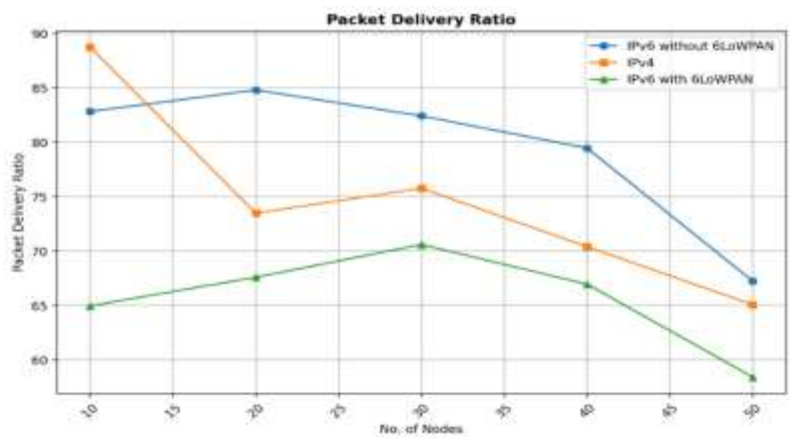

Figure 6. Packet Delivery Ratio (%)

4.2. 6LoWPAN Compression

Our simulation results indicate that AODV when used with IPv6 ends up with a large control overhead. We observe that major portion of this increase is attributed mainly to the presence of protocol headers that encapsulate the protocol control packets, e.g., AODV Route Request is a control packet having two headers, AODV header and IPv6 header. Also, ICMPv6 NS packet is a control packet having two headers, ICMP header and IPv6 header. The headers of all these control packets add up to generate the major chunk of this control overhead for AODV using IPv6.

In order to determine the contribution of data packets towards this control overhead, we also computed the total control overhead generated by IPv6 headers during the transmission data packets. It was done for both cases, i.e., AODV without 6LoWPAN, and AODV with 6LoWPAN compression. The results are shown in Table-1 below, which indicates the impact of 6LoWPAN compression for data packet transmission. We see that for each simulation scenario, the control overhead has significantly been reduced as a consequence of header compression. This verifies the fact that the excessive control overhead of AODV with IPv6 is mainly contributed by the protocol control packets. Therefore, a routing protocol that generates lesser number of control packets can truly benefit from the header compression facility offered by 6LoWPAN specification.

Table 1. Effect of 6LoWPAN Compression over Control Overhead of Data Packets Control Overhead (Kbytes)

Nodes	IPv6 without 6LowPAN Compression	IPv6 with 6LowPAN Compression	Difference
10	198.384	77.808	120.576
20	203.136	80.952	122.184
30	197.424	84.552	112.872
40	190.320	80.184	110.136
50	161.040	69.960	91.08

5. Conclusion and Future Work

The important contributions of this work include, (a) the successful adaptation of AODV to IPv6 based MANETs by extending NS-3 simulator with an additional AODV module that uses IPv6, (b) implementation of 6LoWPAN between IPv6 and WiFi MAC to reduce control overhead incurred during AODV operation due to large size IPv6 headers, (c) evaluation of network performance for AODV with IPv6 and 6LoWPAN in WiFi MANETs and its comparison with AODV using IPv4. Our NS-3 simulations indicate that AODV protocol while using IPv6 can still efficiently route data between mobile nodes in adhoc networks, albeit with an increased control overhead, which can be mitigated, especially for data packet transport, by using 6LoWPAN compression for IPv6 and UDP headers. Therefore, 6LoWPAN though originally meant for LR-WPANs, can also be employed in a WiFi MANET to improve its transmission efficiency. Additionally, the demonstrated operation of AODV with IPv6 broadens the scope of AODV usage in next generation networks, especially in the IoT domain, which essentially requires a large address space not available with IPv4, and also to provide multi-hop connectivity in vehicular networks enabling applications such as cooperative collision avoidance, traffic management, and infotainment services.

This work can be enhanced by applying principles of 6LoWPAN compression to additionally compress AODV headers too, which will result in further reducing the control overhead for AODV operation, thus achieving higher transmission efficiency and lowering energy consumption, a mandatory need for the bandwidth and battery constrained IoT nodes.
Moreover, 6LoWPAN supports IPHC context-based compression but requires the context to be added manually to nodes. This is because the Neighbor Discovery Optimization for IPv6 over 6LoWPANs is not yet implemented in NS-3. As such, NS-3 can also be extended to achieve complete functionality of IPv6 auto address configuration, and the same may be tested for IEEE 802.11 WLANs.

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