Cross-Layer Design Based N-Ary Huffman Coding For Performance Analysis of DSDV Routing Protocol In MANETs

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Research Article

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Abstract

The implementation of the optimal Huffman coding technique for achieving proficient data compression, lower information redundancy and minimal utilization of the scarce bandwidth is essential to handle the effective processing of massive network data. In this paper, we employ cross-layer design technique among the data link, network and presentation layers of the traditional protocol stack to develop the improved DSDV routing protocol based on n-ary Huffman coding procedure. The entropy-based adaptive prefix codewords with variable length are assigned to the probability of packet successful delivery across the ad-hoc wireless network. Several coding and network efficiency parameters are deployed to assess the performance of the proposed routing scheme under three distinctive IPv4 network scenarios. These investigated network protocols include the default IPv4, multi IPv4 and dynamic IPv4 routing methodologies. Diversified simulation settings are employed with deviating network size to measure the multitude of essential wireless network characteristics incorporating the average delay, packet error rate, packet delivery fraction, data rate, ping loss rate, entropy rate, and reception cache hit. In addition, the set of key data compression/coding indicators are examined through comprehensive numerical analysis such as codeword length, source information rate, mean redundancy, and coding efficiency. Beyond, we significantly compare the performance of our developed cross-layer coded mobile routing model with several previous algorithms to validate its enhanced feasibility and superiority in terms of crucial network operation metrics such as throughput, packet drop rate, mean delay and packet delivery ratio.

Introduction

An ad-hoc network is a collection of independent mobile nodes with similar transmission power and ubiquitous computation capabilities that communicate through radio or infrared wireless adapters. These decentralized networks with brief deployment period are established instantly for a specific networking application domain. Such networks are envisioned to provide the required communication mechanism quickly in environments where networks are created and destroyed with little or no planning, such as in a disaster area or in enemy territories. Concretely, mobile ad-hoc networks (MANETs) are distinguished from other ad-hoc networks by potentially highly dynamic and unpredictable topology, determined by mobility nature of the participating nodes and the fluctuating network size. MANETs were originally derived from the Packet Radio Network (PRNET) during early military research in 1972, which then evolved into the Survivable Adaptive Radio Network (SURAN) in 1980’s. The functioning group of MANET is born in Internet Engineering Task Force (IETF), termed the MANET working group, who worked to standardize routing protocols for MANET and gives rise to the development of various mobile devices like PDA’s, palmtops, notebooks, etc. [1] to maintain self-creating mobile ad-hoc networking architecture. Since there is no assistance of explicit server or central controller, MANETs exhibit peer-to-peer communication, such that each node in the network works autonomously and cooperates with other nodes in order to make the whole system operational. Due to quick and inexpensive installation, ad-hoc networks find applications in many areas including collaborative and distributed computing, emergency rescue-and-search operations, military applications, home/personal networking, etc. The Transmission Control Protocol/Internet

Protocol (TCP/IP) suite consisting of two distinct protocols is commonly deployed for network communications in which the TCP protocol at the transport layer is used to transfer legitimate data together with the end-to-end error detection and correction services. Besides, Internet Protocol version 4 (IPv4) is the prevalent network layer routing protocol with broad applications in wireless communications domain. TCP/IP reference model (used in the Internet) is the widely known example of the layered network architecture. In these layered structures, each module/layer within the network stack has a well-defined function and provides certain services (accessible through interfaces) to the next higher layer. It is important to note that changes in one layer do not require changes in other layers of the protocol stack as each layer in the layered protocol stack is probably self-contained and can be implemented independently.

Recent development of wireless technologies like Bluetooth, HIPERLAN, and the IEEE 802.11 Standard (Wireless LANs) identified mobile ad-hoc networking as a new and challenging evolution in wireless technology. The network is ad-hoc because it does not rely on any preinstalled infrastructure for network initialization and operation. Routing is the act of moving information from a source host to a destination host via a number of intermediate hosts in telecommunication networks. Every node in the network that participates in communication performs routing of data traffic through exchange of routing information in order to maintain network connectivity. All nodes can be at the same time function as nodes transmitting and receiving the network traffic (as a terminal node) as well as forwarding the traffic for other nodes (as a router). Wireless nodes in MANET are free to move arbitrarily independent of each other which makes routing much difficult. Due to limited wireless transmission range, absence of centralized entity, and radio power limitation, direct data traffic delivery in a single-hop fashion is generally infeasible. Instead, multi-hop routing occurs in MANET, in which packets sent by source node must be relayed by several intermediate nodes using multi-hop wireless links before reaching the destination node.

Emerging as a next generation of networks, a MANET uses multi-hop approach to deliver data due to limited wireless transmission range of nodes. Hence, MANETs are also called mobile multi-hop wireless networks. Since a MANET has no established infrastructure and is multi-hop in nature, every node in the network functions as a router and takes part in discovery and maintenance of routes to other nodes in the network. All wireless nodes in MANET configure themselves through random movement and cooperate to relay packets through the network. MANET is fully self-organizing, self-creating, self-configuring, rapidly deployable that can dynamically be set up quickly in any environment. Routing in MANETs is a challenging issue since it is characterized by mobile computing nodes, open error-prone medium, dynamic network partitioning, low capacity wireless links, infrastructure less ad-hoc environment, frequent link failures, and multi-hop wireless connectivity. Moreover, developing a reliable and scalable routing over MANET is a very critical task due to resource-constrained devices and highly dynamic environment. Because of frequent changes in network topology and without prior notice, efficient design and performance of routing protocols in MANETs is an important issue.

In order for communication to take place within the network, a routing protocol is used to discover routes between the computing devices in a MANET. The primary goal of an ad-hoc network routing algorithm is to optimally establish a route between a pair of nodes in the network so that a message can be delivered to the correct destination according to the quality of service desired within the expected time. Moreover, route computation and maintenance should be done with a minimum of control overhead and bandwidth consumption.

Over the last 10 years, various MANET routing protocols have been proposed by network researchers and designed primarily to improve the MANET performance with respect to establishing correct and efficient routes between a pair of nodes for packet delivery [2]. Here, we utilize the widely applicable proactive destination-sequenced distance-vector (DSDV) routing mechanism for hop-by-hop transmission of data packets through the ad-hoc network assisted with up-to-date topological view. This protocol necessitates each mobile node in the network propagates the updated routing information at regular time intervals by exchanging the routing table with other nodes. This ensures the data coherence, renewal and sustainment of the stored database in the form of routing table entries. It has been successfully deployed in dynamic packet switched networks without the intervention of any central controller entity. This data forwarding strategy eliminates the tendency of generation of routing loops by employing the sequence number information originated and regularly updated by the destination node. The obsolete routes are replaced by the latest path discovery through the sequence number entry in the routing table exchange to establish communication between the specific nodes in the ad-hoc network.

Furthermore, in this work, we employ the IPv4 protocol family with its three variants, viz., the default IPv4 protocol, the multi IPv4 protocol and the dynamic IPv4 protocol. These protocols transmit data traffic in the form of isolated datagrams across the wireless network through unreliable, connectionless and hop-by-hop delivery mechanism accompanied by the store-and-forwarding principle. If the datagram exceeds the maximum size limit, it is typically split into smaller fragments. These are transferred independently to the destination node where the original IP datagram is reassembled from the received individual fragments across each path.

The default IPv4 network protocol operates at the network layer of the stack architecture and enables distinctive host identification connected to the web. It comprises of the dominant set of rules for data communication through route establishment for supporting the tremendous Internet traffic. This data transmission path is shared among the numerous wireless networked devices via packet switching mode for the public Internet access. In multi IPv4 network layout, the default IPv4 routing is employed on multiple network protocols with advanced network configuration. The application program transmits the IP packet to multiple nodes. This packet is comprised of both a fixed-length header information facilitating the routing process and variable-length actual data payload. Also, in dynamic IPv4 setting, some nodes are shut down and restarted when path request arrives from the incoming data packets. This path establishment phase using DSDV routing triggers the route modifications adaptively.

The rest of the paper is organized as follows. In the next section, we briefly describe the DSDV routing scheme in MANETs and cross-layer paradigm for efficient operation of wireless technologies. We review the related research work previously existing in literature in Sect. 3. Section 4 describes the designed system model. In Sect. 5, we have presented the network setup and the simulation environment for conducting the experiments for the proposed cross-layer design based DSDV routing protocol. The simulation results and the associated analysis of various performance indicators are discussed in Sect. 6. Finally, conclusions of the research work together with the potential future research directions are presented in Sect. 7.

Background

In this section, we introduce the preliminary concepts of the DSDV routing mechanism and cross-layer design implementation for ad-hoc networks.

2.1 DSDV Routing Protocol

The DSDV routing scheme is based on the traditional Bellman-Ford technique [3]. This data transmission protocol employs classical routing strategy of the distance-vector based routing algorithm which periodically floods the connectivity related link information about its neighbours. This table-driven and proactive data forwarding algorithm periodically updates consistent routes to all the reachable nodes in the ad-hoc network. Data packets are routed through the network via the distributed multi-hop relaying approach without the support of any centralized administration.

Each node in the network keeps track of all the accessible routes by maintaining a route entry to every other node in a data structure called routing table, hence these protocols are sometimes referred to as table-driven protocols. In proactive routing, every node continuously learns, evaluates and maintains the complete routing information of the network topology. Routes are readily available whenever there is a request to send packet to any other node in the network, thus route to destination is predetermined and does not incur any delay for route discovery. Since a route to every node in the network is always available, this approach causes no initial delay in communication. Such protocols are named proactive protocols since the routing information is maintained, updated and exchanged constantly irrespective of its requirement. Updated routing information is periodically flooded in the network as the network topology changes. The proactive algorithms maintain a consistent view of the network at all nodes through the propagation of topology updates throughout the network at fixed time intervals, regardless of mobility and medium characteristics of the network. As a result, this routing strategy consumes lots of network resources since more control packets are involved to maintain consistent network topology information, resulting in slow transmission rates.

Furthermore, if the topology of the network changes too frequently, the cost of maintaining the current up-to-date topological information among the network nodes might be very high. On the other hand, if the network activity is low, then the routing information might even not be used for unused links. The impact of network scalability issue needs to be explored for the pure proactive scheme as every node’s routing table maintains the current route entries for each and every node even when not required. This may lead to relatively more communication overhead on the network and higher bandwidth utilization.

2.2 Cross-layer Design

Recently, the design of modern wireless networks typically deploy considerable exchange of crucial data between various layers of the conventional networking stack effecting the significant performance of protocol implementations. Cross-layer or interlayer networking can be defined as modification of the layered reference architecture to achieve the desired vertical optimization goal. Contrary to the layered architecture in which a layer does not share information about its state with any other layer, the basic purpose of cross-layer design is to actively exploit relevant knowledge from multiple layers to attain performance gains in terms of throughput, average end-to-end delay, etc. The system performance of next-generation wireless networks will be optimized by cross-layer design between physical, MAC and higher-layer protocols. Cross-layer architecture can be considered as new interaction model in which there are some functions or services that are not linked to a particular layer, but they can influence more than one layer.

Exploitation of cross-layer design for routing in MANETs has demonstrated remarkable potential. Protocol design by the violation of a reference layered communication architecture is cross-layer design with respect to the particular layered architecture. Cross-layer deign represents a suitable technique to overcome the limitations of the traditional layered approach by allowing interaction between communication protocols crossing different layers. To deal with the unique challenges of wireless ad-hoc networks and to optimally utilize the limited resources of the resource-constrained mobile nodes, the concept of cross-layer design is employed. The motivating factors for adopting the principle of cross-layer design for MANETs include the wireless link properties such as channel errors, novel modalities of communication, opportunistic communication over the wireless medium, inherent layer dependencies, node mobility, security attacks by intruders in the wireless network, etc. Rigid layer disjointedness in the traditional layered architecture forbids direct communication among layers to make mutual decisions. Hence, optimized cross-layering is required for a more flexible information flow across the layers in the protocol stack.

There are six different types of cross-layer design implementations typically deployed in wireless network architectures. Many of the cross-layering proposals necessitate designing new interfaces between the layers for dynamic sharing of information. Based on the direction of information flow along the new interfaces, this category is subdivided into upward, downward and back-and-forth information flow designs. In the upward information flow, a new interface is created that forwards the information from one or more lower layers to the higher layer. In contrast, the information flow from some higher layer to a lower layer using a direct interface is the downward information flow. The back-and-forth information stream refers to the data flowing to-and-fro between two layers performing different tasks. A combination of adjacent layers can be merged into a single optimized superlayer, such that the service provided by this new layer is the conglomeration of functionalities provided by the individual layers. In cross-layer data exchange coupling with no new interfaces, various layers are coupled at design time without creating additional interfaces. Finally, cross-layer paradigm can be executed via the vertically calibrated designs that involve joint tuning of the parameters at all protocol layers.

Related Work

From the literature survey, it is found that thorough performance assessment of various routing schemes in miscellaneous wireless network development has been conducted in the past for efficacious information delivery. Tripathi et al. [4] explored the DSDV routing scheme in stationary sensor networks with dynamic source-sink node pair. The effectiveness of the developed system operation is observed through the byte delivery fraction and end-to-end delay evaluation under varying node density and speed characteristics. Work in [5] estimated and compared the performance of the proactive Optimized Link State Routing protocol (OLSR), reactive Ad-hoc On-Demand Distance Vector Routing (AODV), and reactive Dynamic Source Routing (DSR) applied to the practical motorway surveillance system with infrastructure-less freeway mobility scenarios. The authors in [6] investigated the performance of high-bandwidth video streaming applications over real-time MANETs implemented with multiple routing protocols. Likewise, the video streaming services using temporal scalability is effectuated with prevalent path establishment for network traffic load and message forwarding procedures in [7]. These include the general AODV, DSR, DSDV and Multipath AODV protocols for analyzing the quality of experience for supporting the customer demand and enhanced multimedia coding efficiency with route maintainability over the decentralized real-time ad-hoc environments.

Hao et al. [8] surveyed the performance of three distinct routing protocols, viz. DSDV, AODV, and DSR in wireless sensor network using the NS-2 simulation tool. They analyzed the evolvement of four performance metrics with the advancing network density. The authors in [9] evaluated the performance of AODV and DSDV routing algorithms for route discovery and maintenance in the presence of cooperative as well as isolated black-hole attacks. For this, the routing and congestion overhead are computed conforming to the progressive network scale along with the end-to-end delay valuation in ad-hoc environment. Additionally, the operation of AODV, DSDV and OLSR routing techniques are investigated in smart vehicular ad-hoc communications [10]. Disparate performance metrics are estimated based on the BonnMotion mobility setup scenario according to the variation in the node density, node velocity, and simulation trajectory area. Pradhan et al. [11] proposed a novel distributed and cooperative routing methodology for mobile wireless sensor network with probably frequent link failures. This scheme is aimed at finding robust paths for data transmission between the intended source-destination node pairs.

Gupta et al. [12] carried out the relative assessment of three contemporary routing protocols in MANET, viz. AODV, DSDV and DSR with progressive simulation duration and mobile environment in terms of packet delivery, throughput and delay specifications. The body of work in [13] surveyed the performance analysis of several popular routing protocols including the proactive, reactive and hybrid networking technologies for sending information over the wireless network. Kumar et al. [14] analyzed the performance of various ad-hoc unicast routing schemes in MANETs using the dynamic Qualnet simulation software. This network model interpretation is subjected to the conventional path discovery and route maintenance mechanisms accompanied by Constant Bit Rate (CBR) traffic application. An energy-proficient source routing protocol for heterogeneous resource-restrained wireless sensor network is developed to identify minimal cost route for unicast information transfer [15]. Vasundra and Venkatesh

[16] computed the performance comparison among the AODV, DSR and Temporally Ordered Routing Algorithm (TORA) techniques for adaptive route creation through the simulation experiments to implement voice and video traffic applications in mobile wireless technologies. The authors in [17] contrasted the functioning of AODV, DSR, OLSR and TORA routing protocols under varying traffic load scenarios and device mobility conditions using the Opnet Modeller.

Additionally, cross-layer optimization and network coding schemes for ad-hoc wireless systems have received considerable research interests in recent years. Our previous work [18] focused on the cross-layer paradigm based on the consolidated network coding design and optimal resource allocation to restrained wireless communication links in random-access wireless systems. This framework utilized non-linear programming formulation with multiple constraints for achieving stable entropy and resource allocation fairness measures in challenged wireless networks. In another preceding work [19], we deployed cross-layer design among four layers of the network protocol stack and applied adaptive Huffman coding technique to node persistence probabilities in wireless ad-hoc network. This multiple-flow network scenario executed with random waypoint mobility for generic routing scheme adopted convex optimization model to retrieve optimal data compression and network service quality parameters. An energy-efficient on-demand routing mechanism for network lifetime maximization and minimal packet drops in MANETs is presented in [20] by devising enhancement to the current DSR protocol. Hussein et al. [21] formulated a robust routing model based on the heuristic greedy paradigm for wireless multimedia sensor networks. This multipath routing protocol achieves energy conservation and throughput efficiency while configuring the optimal data transmission paths. Furthermore, AODV and DSR routing schemes are examined in realistic vehicular ad-hoc network scenario with discrete-time urban mobility simulation modeling [22].

3.1 Contribution

Our work differs from the aforementioned works in that we address and focus on the joint optimal design of cross-layer medium contention control, routing, and adaptive data compression techniques with distributive implementation. To the best of our knowledge, the work presented in this paper is the first attempt which involves synchronized investigation of the three specified problems in a single consolidated modeling scheme. The interaction among the three respective layers results in the augmented performance of the proposed cross-layer approach over the classical isolated consideration of specific wireless network issues. We analyze the DSDV routing performance under various optimal coding implementations and IPv4 network protocol operations in miscellaneous simulation environments. A series of extensive simulation experiments is designed and performed to assess the aggregate effective enhancement of the diversified network service and data encoding parameters using different network size, network protocol types and generalized coding schemes. Finally, the formulated DSDV protocol based on the unified approach of cross-layer optimization and generalized lossless Huffman coding scheme for optimal data compression is thoroughly compared against the previous routing algorithms. The potential efficiency gains of our work can be substantiated through the disparate simulation collation results which proved the greater throughput, minimal round trip delay, decline in packet collisions and subsequent failures, and sustained data traffic provisioning.

System Model

Figure 1 depicts the schematic representation of the deployed cross-layer design model. This framework employs information exchange among the data link, network and presentation layers of the standard networking stack architecture. The integrated optimization design contemplates the medium access coordinations, routing flow control and data coding issues encompassing the above mentioned three protocol layers. The packet successful transmission probability from the data link layer is fed to the DSDV routing protocol at the network layer through the upward information flow implementation of the cross-layer design. The three network protocol scenarios of the basic IPv4, multi IPv4 and dynamic IPv4 are employed and simulated within the ad-hoc routing methodology of the proactive DSDV technique. In addition, the packet success probability from the data link layer is used by the Huffman coding algorithm at the presentation layer for data coding and compression. We employ three coding schemes on the similar network data, viz. binary, ternary and quaternary coding methods to assess the performance analysis of the joint implementation of the dynamic cross-layering and the optimal information coding principles. Several key metrics to evaluate the efficiency of the proposed DSDV routing scheme based on the combined design of cross-layer optimization and n-ary Huffman coding procedures is presented. These parameters associated with the wireless data communications incorporate the average entropy rate, reception cache hit, round trip delay, mean packet error rate, packet delivery ratio, data transfer rate and ping loss rate. Moreover, in later sections, we provide the detailed estimation of distinctive data coding characteristics such as average codeword length, expected redundancy, source information rate and coding efficiency to measure its impact on the modified DSDV protocol.

Fig. 2 represents the binary, ternary and quaternary Huffman prefix-free and variable-length code trees. The symbols connected with each leaf node in the individual trees constitute the optimal codes conforming to the probability of packet successful transmission for various nodes in the ad-hoc network. These symbols comprise of the binary digits (bits), ternary digits (trits), and quaternary digits (quatrits) associated with the binary, ternary, and quaternary Huffman coding trees. Observe that as the number of digits utilized in the Huffman coding procedure increases, the average number of symbols assigned to individual leaf nodes representing the probability of packet successful delivery in ad-hoc networks decreases. Besides, the number of levels in the Huffman coding tree also diminishes, thereby improving the coding rate and information compression efficiency.

4.1 Contention-prone MAC and Network Layer Models

In this work, an ad-hoc wireless network is modeled as a directed graphical structure comprised of non-stationary nodes interconnected by a set of wireless data links. Assuming that each link is represented by an Additive White Gaussian Noise (AWGN) channel allocated with the necessary frequency bandwidth for packet forwarding, it supports the single-hop communication between the distinctive transmitter and the receiver nodes. It is deduced that the interference between neighbouring nodes over the operational bandwidth is insignificant relative to the ambient noise levels measured at the receiver. These noise standards for the considered discrete-time channel with quantized digital signal output are drawn independently and identically distributed (iid) from the random Gaussian distribution.

We adopt a contention-control random-access protocol at the MAC layer which is based on the binary exponential backoff algorithm [23]. This IEEE 802.11 based wireless local area network (WLAN) standard employed the carrier-sense multiple access with collision avoidance (CSMA/CA) technique to prevent packet collisions, and accomplish throughput optimization in ad-hoc networks. Assume that time is divided into discrete slots, each of equal duration, such that each node begins its data transmission only at the start of its assigned slot. When a node wants to transmit data, it contends for the access to the shared medium with a certain persistence probability. In this wireless channel admission and cooperative coordination strategy, a node with data to transmit senses the channel status for a specific time interval. If the channel is experienced to be busy during this duration, the node suspends its transmission. Otherwise, the node transmits the packet through one of its outgoing links and consequently waits for the acknowledgement frame. Adaptable collection of wireless nodes are arbitrarily deployed in a two-dimensional rectangular topological region of 1000 * 500 square meters. Nodes employ multi-hop routing to communicate with each other via wireless links implemented with TCP connections.

It is presumed that CBR traffic sources originate and transfer application data, necessitating the service quality assurance to implement the session-based admission control mechanism of new traffic flow sessions arriving into the heterogeneous network platform. Information generated by the source is converted into some form of electromagnetic or optical signals before transmitting it through the communication medium. These data traffic conditions are typically specified through the appropriate probability density function (PDF) and certain acceptable packet loss levels. In the worst case scenario, sessions are admitted into the network based on their peak flow rate demand. TCP/IP is the software implemented in each wireless node that is used to activate the interconnection among the internetworking devices to establish the two-way data communication process. Moreover, the underlying channel is assumed to follow the flat Rayleigh fading model with frequency non-selective characteristics for determining the dynamic response of wireless systems over intermittent packet losses encountered in the midst of the packet transmissions by various nodes.

Simulation Setup Environment

OMNeT + + discrete-event simulation framework coupled with the Qtenv set up is utilized to conduct the miscellaneous analytical experiments [24]. Multiple Network Description (NED) files are loaded and various NED parameters are adaptively estimated for assessment of optimal performance metrics associated with the presented coding-based DSDV routing methodology. Based on the flexible Eclipse platform [25], OMNeT + + Integrated Development Environment (IDE) is deployed for conducting discrete-event simulations. This modular simulation environment incorporates the Mobility framework (MF) [26] to reinforce the generalized execution of the mobile wireless networks by development of advanced networking protocols within the simulation tool. In addition, it includes the open-source model library of the INET framework [27] specified by different hierarchical module configurations which comprises of widely popular IPv4, IPv6, TCP, SCTP, UDP protocol deployments, and numerous application and link-layer models. The network model is designed, executed and the corresponding results are analyzed via the NED and the Initialization File (default omnetpp.ini).

The proposed model development is implemented and simulated in the Qtenv environment through the interactive graphical runtime interface. It incorporates the network visualization properties, object inspection, message flow animation and eventlog recording during simulation, etc. While the simulation is running, the output is displayed in the log viewer window, which represents the embedded log level of individual specific modules and the message traffic details.

We suppose that the free-space path loss model is employed for the radio signal propagation and radiation by the omni-directional antennas. The TCP scheme is utilized for the end-to-end reliable connection-oriented delivery of message streams along the unreliable internetworking implementation over the IP model. This modeling scenario deploys the 32-bit logical addresses to facilitate the wireless host identification followed by the expected data routing with best-effort delivery mechanism over the underlying network to reach the desired destination node in an optimum manner. The spectrally-efficient and rate-adaptive digital modulation process of Binary Phase Shift Keying (BPSK) [28] is used with a communication channel bandwidth of 22 MHz.

The timespan taken by routing host to transmit successive hello packets across the cooperative IP network through the logical interface is 5 seconds. This is also the duration of the route timer along the way to the intended destination. The simulation of mobile systems is analyzed using the steady-state distribution of nodal speeds and distances. This is enforced until congregation to particular long-term average of unconstrained transient interval of maximal transmission period of 10 ms. The center frequency of the coded caching scheme in the frequency shared communication mode is taken as 2.4 GHz.

Table 1
Basic simulation parameters.

Parameter	Value
Topological Area	1000m x 500m
Simulation Software	OMNeT++
Channel Type	Wireless
Network Topology	Random
Number of Nodes	5–80
Node Mobility	Stationary Mobility
Application Layer Utility	Ping
Ping Start Time	Uniform (1s,5s)
Application Layer Protocol	CBR
Transport Layer Protocol	TCP
Network Layer Protocol	IP
Routing Protocol	DSDV
MAC Layer Protocol	IEEE 802.11 DCF
Physical Layer Protocol	IEEE 802.11
Minimum Congestion Window Size	7
Antenna Model	Omni-directional
Maximum Antenna Gain	0 dB
Modulation Scheme	BPSK
Initial Bit Rate	2 Mbps
Simulation Time	40 seconds
Radio Transmitter Power	2 mW
Propagation Speed	299.79 x 10^6 mps
Background Noise Power	-110 dBm
Path Loss Model	Free Space
Path Loss Coefficient	2
System Loss	0 dB

Parameter	Value
Bandwidth	22 MHz
Cache Center Frequency	2.412 GHz
Minimal Reception Power	-85 dBm
Minimal Interference Time	1 ps
Maximum Transmission Duration	10 ms
Queue Capacity	100 packets
RTS Threshold	2346 Bytes
MAC Frame Header Length	192 bits
Packet Size	56 Bytes
DSDV Hello Interval	5 seconds
DSDV Route Lifetime	5 seconds
IPv4 Processing Delay	0 second
IPv4 Cache Timeout	120 seconds
Retry Count	3
Retry Timeout	1 second
Time To Live	32
IPv4 Fragment Timeout	60 seconds

We assume that there is no processing time associated with each arrived IPv4 datagram at a node. The time interval amidst the retries for IPv4 address resolution is 1 second, and attempting frequency to interpret the IPv4 address is 3. The time to live parameter for unicast datagrams is set to 32. Maximum period of time for which the fragments are stored in the fragment queue until they are transmitted is kept as 60 seconds. Table 1 illustrates the various simulation parameters together with their corresponding values deployed in the proposed system model setup and operationalization.

Simulation Results And Analysis

In this section, we investigate the performance of the proposed coding-based DSDV routing algorithm by conducting simulations in the communication network simulation package of the extensible OMNeT++ software tool. This routing protocol is implemented with the cross-layer design methodology. The mobile wireless ad-hoc network with arbitrary distribution of nodes located in a rectangular topographical area is demonstrated in Fig. 3. The displayed DSDV network consists of various INET modules including the Scenario Manager, IPv4 Network Configurator implemented at the network layer, IPv4 Routing Table

Recorder at the network layer, DSDV Router, and IEEE 802.11 Scalar Radio Medium at the physical layer, in addition to multiple wireless nodes. This network scenario is implemented in the simulation software to examine the execution of the proposed cross-layer optimized DSDV protocol. The 32-bit binary subnet mask specifying the range of IP addresses for the considered IPv4 protocol layout is 255.255.0.0. Figure 4 shows the evolution of the average packet error rate with the network size for different IP protocols. It can be estimated that the multi IPv4 protocol exhibits maximal packet error rate with the mean value of 0.382. However, IPv4 and dynamic IPv4 protocols show a decline in packet error rate by around 16.52% and 15.37%, respectively.

Fig. 5 illustrates the evolving histogram of the average entropy rate for the contemplated network layer protocols plotted against the number of wireless nodes. The entropy rate for the IPv4, multi IPv4 and dynamic IPv4 routing schemes averaged over the employed range of the network size is computed as 0.011, 0.013 and 0.0119. As a measure of the uncertainty of wireless system information in terms of data packets generated by the source hosts, multi IPv4 protocol represents the maximum randomness of the application level information characterized by highest value of the discrete entropy. Plots of the achievable source information rate for disparate IP protocol implementations is represented in Fig. 6. It can be observed that the multi IPv4 protocol has the highest information rate with the mean value of 59.52 Mbps over the specified network scale set up scenario. Moreover, this rate performance is relatively 12.1% and 6.7% greater than the IPv4 and dynamic IPv4 routing technologies. This considerable improvement in multi IPv4 protocol operation can be attributed to the larger entropy rate and significant uncertainty associated with the network data traffic and mobility conditions in this particular network protocol instance.

In Fig. 7, the reception cache hit parameter obtained via various deployed network protocol types is graphically presented. The IPv4, multi IPv4 and dynamic IPv4 protocols correspondingly signify the data access and transmission cache rate values of 82.82, 83.2, and 82.87. In this case as well, the multi IPv4 methodology outperforms the other two routing schemes by a maximal ratio of 1.0046 in the context of successfully received packets. Further, Fig. 8 demonstrates the packet delivery ratio metric of distinct network communication protocols amending with the number of nodes in the wireless network. This key performance indicator for networking management and application is measured as the ratio of the successful data delivery across the wireless medium to the total number of packets originated by the source nodes in the network. The basic IPv4 protocol corroborates the greatest possible average estimate of the packet delivery ratio of 7.084. This is moderately curtailed by 9.04% and 1.93% in accordance with the concrete multi IPv4 and dynamic IPv4 network protocols.

Fig. 9 shows the evolution of the mean round trip time associated with the packet transmission over the network using the employed Internet protocols. This delay parameter for the envisaged network scale scenario is efficaciously optimized in IPv4 routing scheme with the expected value of 154.08 ms. The end-to-end delay approximation for the primitive IPv4 approach is ameliorated by factors of 2.196 and 1.338 as regards to the multi and dynamic IPv4 path selection and data forwarding techniques, respectively. The percentage of ping loss statistics for different IPv4 protocol types is represented in Fig.

10. It indicates the network availability status and losses in connectivity for specific multimedia streaming applications that affect the wireless signal quality. The Packet Internet Groper (PING) is an application layer utility to ensure the Internet accessibility across the network and correct operation of the TCP/IP protocol suite. The multi IPv4 protocol signifies the worst-case ping loss performance substantiated by 57.07%, while the best-case operation with least ping loss ratio is exhibited by the dynamic IPv4 scheme with valuation of 19.38%.

Fig. 11 depicts the variation of the average codeword length retrieved with the binary, ternary and quaternary coding techniques implementation with the distinctive IP data routing protocols as a function of the network size. As n increases, the average codeword length for modeling the packet success probability of each individual node decreases. It can be computationally estimated that the quaternary Huffman coding executed with the multi IPv4 protocol establishes the minimal average codeword length of 78.03. This is upto 52.23% more efficient than the largest average codeword length acquired by the IPv4 protocol applied within the framework of binary Huffman coding. The redundancy of various n-ary Huffman coding algorithms applied to different IP protocols altering with the increase in number of nodes is plotted in Fig. 12. This information-theoretical metric is measured by the difference between the average codeword length and dynamical entropy of the discrete probability distribution. For IPv4 protocol, the quaternary coding scheme exhibits 55.97% and 13.89% reduction in mean redundancy as compared to binary and ternary coding methods, respectively. The quaternary Huffman coding shows the alleviated redundancy measure by around 56.58% for binary and 16.1% for ternary coding procedures in case of multi IPv4 routing scheme. Likewise, for dynamic IPv4 protocol, the optimal quaternary coding algorithm applied to the proposed system model obtains 56.27% and 14.08% lower redundancy measure in contrast to the binary and ternary coding schemes, respectively. The optimal performance of quaternary coding over the ternary and binary codes emanates from the lessened number of internal nodes in the Huffman coding tree connected with minimal path length from the root node to the farthest leaf nodes. This results in greater compression of network related information and more effective coding design to represent the same data using lesser number of quatrits corresponding to quaternary numeral digits. Moreover, the multi IPv4 protocol implemented with quaternary coding design indicates 20.07% and 14.94% mitigated redundancy corresponding to the IPv4 and dynamic IPv4 protocols. This validates the most efficient performance of the multi IPv4 protocol as compared with the other two studied internetworking protocols in terms of the coding metrics of average codeword length and mean redundancy.

In Fig. 13, the attained data rates for disparate coding algorithms applied to the multiple IP protocols is depicted with the varying network scale. The highest network data rate achieved over the wireless communication channel with binary Huffman coding correlated with the IPv4 routing methodology is estimated to be 326.67 Mbps. This is analogously 13.715% and 3.55% higher than the multi IPv4 and dynamic IPv4 data transfer techniques operated with the binary tree for encoding scheme. On the contrary, quaternary Huffman coding executed with the multi IPv4 protocol evinces the least data rate requirement of nearly 156.05 Mbps, lowered by a factor of utmost 2.093. Further, Fig. 14 illustrates the coding efficiency metric associated with different coding schemes applied to various IPv4 protocol types evolving with the number of nodes in the wireless network. It can be deduced that the coding efficiency is maximized in the context of multi IPv4 protocol using the quaternary prefix code with the expected value of 0.272. This is attenuated by 14.96% and 9.36% with respect to quaternary coding implementation for the basic IPv4 and dynamic IPv4 routing strategies. The ternary coding applied to multi IPv4 algorithm achieved 17.6% and 12.13% higher coding efficiency measure when compared with the IPv4 and dynamic IPv4 routing. The modest optimal binary encoding implementation of multi IPv4 having mean coding efficiency of 0.204 is amplified accordingly by the factors of 1.81 and 1.4547 when compared with the IPv4 and dynamic IPv4 routing procedures. Therefore, for generalized n-ary Huffman coding mechanism, the multi IPv4 protocol outperforms the primary IPv4 and dynamic IPv4 routing schemes in terms of minimal required data rate for information transmission, and coding attributes comprising of the optimal codeword length, mitigated redundancy, and improved Huffman encoding efficiency.

6.1 Performance Comparison with Previous Works

In this subsection, our modified DSDV protocol based on the integrated framework of coding optimization and adaptive cross-layer information exchange is compared via simulations with the thirteen earlier works existing in literature in terms of significant network performance attributes including throughput, packet loss rate, data delivery ratio and delay metrics. This performance comparison showing how our developed routing optimization methodology outperforms the earlier works with the identical network environment setup is demonstrated in Table 2.

The packet loss rate denotes the number of packets dropped in the network per simulation time owing to node failures, network partitioning, routing loops, collisions, channel errors and link breakages. This is validated by the route error messages and succeedingly resolved by the packet retransmission from the sender to the receiver node via alternative optimal route. It can be estimated that the presented routing protocol exhibits upto 98.49% reduced packet loss rate than the previous models. Besides, packet delivery ratio is the proportion of the quantity of CBR packets received at the destination to the total number of packets sent by the CBR source. This metric directly impacts the attainable throughput in the wireless network. Our developed routing methodology acquires higher packet successful transmission index by more than 94%. In addition, the throughput of the wireless network is measured by the total number of data bits transmitted through the wireless medium within the operational simulation time. The average throughput measured using the cross-layer design based DSDV routing scheme is improved by at least 78.91% contrary to the contemplated preceding works. Also, the average end-to-end delay is estimated as the time taken by the information packets to be successfully delivered to the destination node. Our proposed work demonstrates lower value of this latency metric by the most optimum factor of 60 compared to other existing networking models. This is due to the shorter paths traversed by the network packets and the associated shorter compressed information bits in the proposed system.

Table 2
Performance comparison of the proposed model with previous existing models.

	Throughput (Mbps)	Packet Loss Rate	Average Delay (seconds)	Packet Delivery Ratio
Our Model	326.67	0.3189	0.154	7.084
Model in [4]	56.4	15.82	0.218	0.937
Model in [5]	0.08	13.7	1.043	1.008
Model in [6]	22.48	5.62	2.35	1.75
Model in [7]	0.942	3.275	3.83	0.69
Model in [8]	0.031	11.84	5.872	0.98
Model in [9]	6.1	1.424	0.0117	0.914
Model in [10]	0.12	0.425	0.473	0.85
Model in [11]	0.58	1.94	0.83	0.7
Model in [12]	68.89	1.72	0.296	0.75
Model in [17]	2.65	9.25	0.4	0.43
Model in [18]	0.018	1.08	2.25	0.4
Model in [20]	1.98	21.2	9.23	0.948
Model in [22]	35.8	14.5	1.75	0.49

Conclusion

In this work, we show that the cross-layer optimization technique employing three layers of the protocol stack can be used to model and implement optimal data coding-based DSDV routing protocol in MANETs. Multiple network performance indicators involving the average round trip delay, mean packet error rate, packet delivery ratio, data transmission rate, ping loss rate, entropy rate, and reception cache hit are computed and experimentally assessed through rigorous simulation analysis. Besides, the key information coding metrics such as codeword length, source information rate, mean redundancy, and coding efficiency are evaluated to measure the impact of network data routing with the varying system scale setting. The effects of these attributes is surveyed for disparate Huffman coding algorithms executed at the presentation layer and various IPv4 routing procedures implemented at the network layer.

These protocols utilize the packet success probability from the data link layer to carry out the enhanced routing and coding schemes in the proposed DSDV routing method. It was estimated through the simulation experiments that the default IPv4 protocol exhibits the minimal packet error rate of 0.318 and largest packet delivery ratio of 7.08 over the considered range of the network size. Also, the average round trip delay of the basic IPv4 scheme is considerably reduced by 54.47% and 25.3% in accordance with the multi and dynamic IPv4 routing procedures. Besides, the multi IPv4 technique indicates the higher entropy rate, reception cache hit, and source information rate due to frequent topology changes and uncertain network traffic conditions. As the number of wireless nodes in the network increases, the dynamic IPv4 routing algorithm outperforms the other two data forwarding schemes with respect to improving the ping loss ratio by upto 66.03%.

The quaternary-coded multi IPv4 protocol demonstrates the enhanced proficiency by achieving 9.84% and 7.7% reduction in average codeword length as compared with default IPv4 and dynamic IPv4 to represent the packet successful delivery probability of each wireless node. Additionally, multi IPv4 methodology executed with the quaternary coding scheme indicates minimal redundancy performance by more than 20%, minimal data traffic rate by upto 52.2%, and enhanced coding efficiency by around 58.5%. Finally, the designed protocol is extensively compared with the previously proposed routing schemes to corroborate the enhanced effectiveness of our work. From the simulation comparison results, we witnessed that our model has higher throughput by a minimal factor of 4.742 and upto 98.33% alleviated network latency than the other reviewed methods. Beyond, the packet delivery ratio is intensified by approximately 94.35% (best-case) and 75.3% (worst-case), whilst the packet drop rate is lowered by a maximal proportion of 66.47 in contrast to the prior existing works.

In the future work, we plan to explore the presented routing algorithm for multi-hop and multiple-flow networking scenarios subjected to the receive diversity techniques, multi-carrier data encoding and modulation, with coherent detection and carrier aggregation to facilitate the spatial frequency reuse and improved reliability in next-generation wireless systems. Further, the considerable effects of node lifetime maximization, time-varying channel fading and outage conditions on proposed cross-layer framework will be investigated. In addition, it is suggested to utilize the evolutionary optimization heuristic procedures including genetic algorithm, ant colony optimization, particle swarm optimization, etc. for effective implementation of the proposed Huffman coding based DSDV routing mechanism.

Declarations

Funding

Not applicable

Conflict of Interest

The author states that there is no conflict of interest.

Availability of data and material (data transparency)

Not applicable

Code availability

Not applicable

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Figures

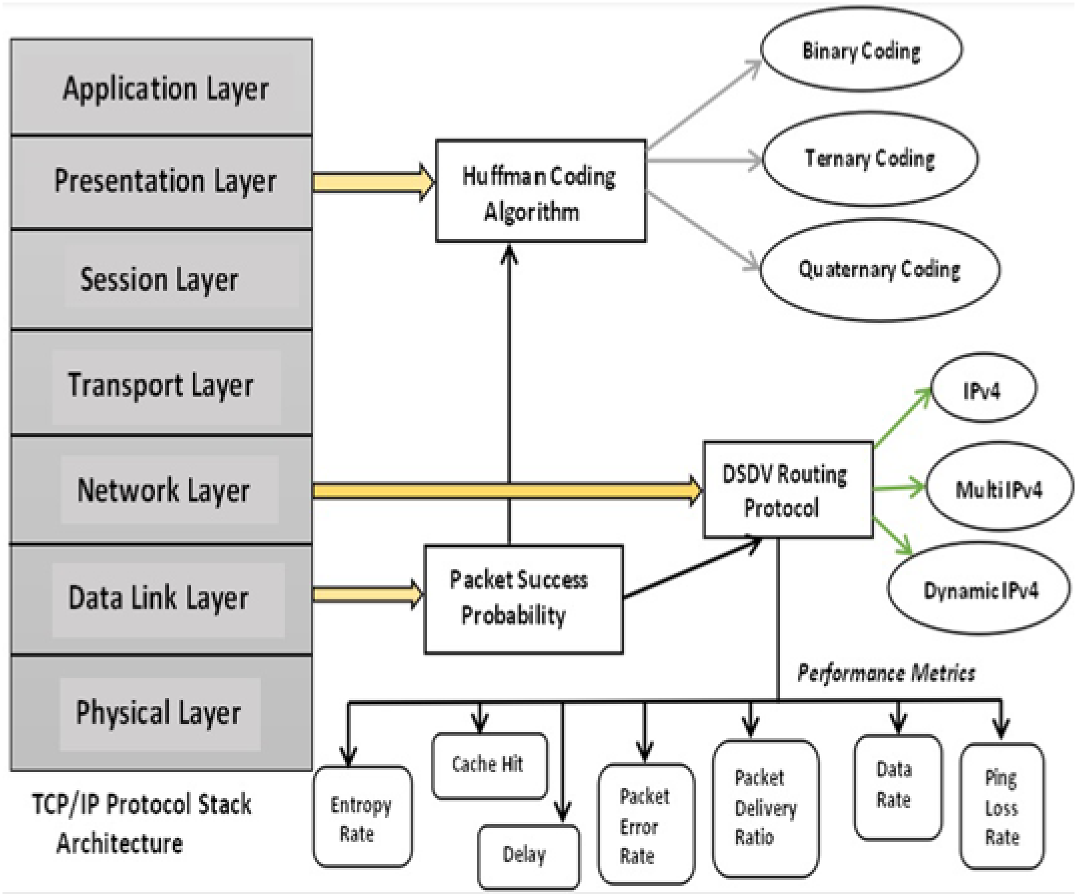


Figure 1

Schematic of the proposed cross-layer design model.

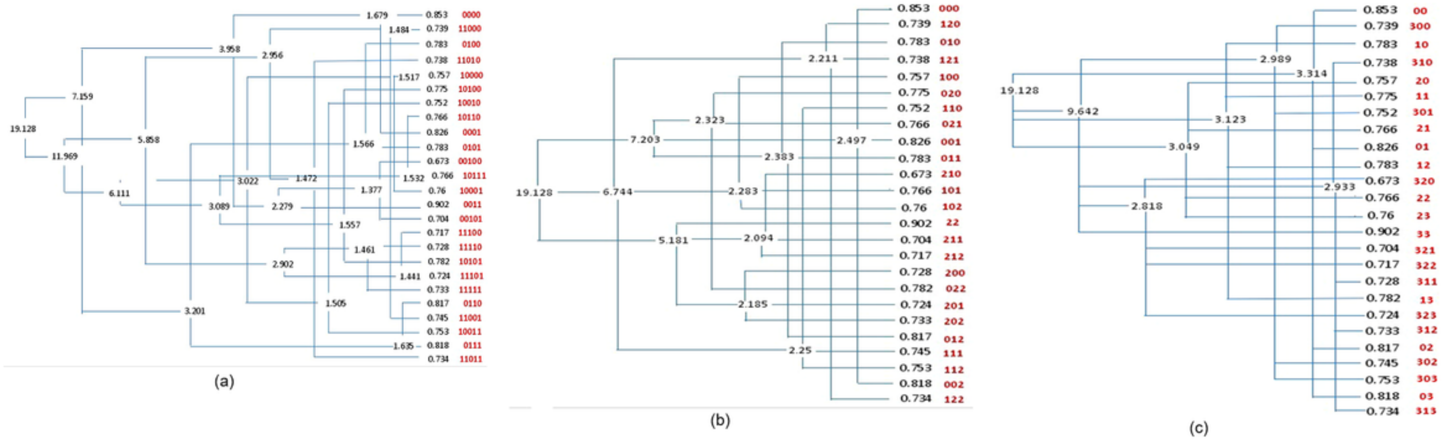
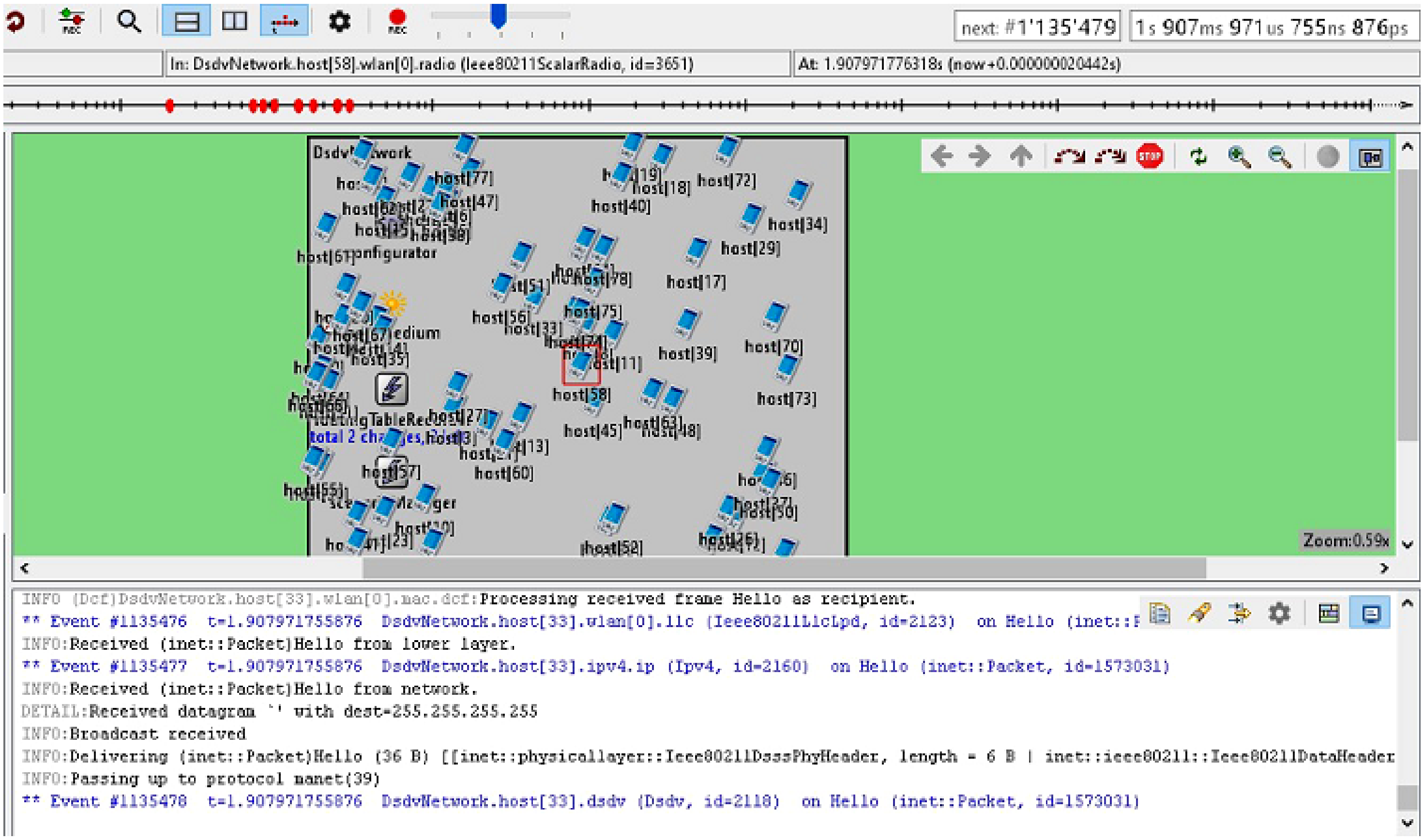


Figure 2

Huffman (a) binary, (b) ternary, and (c) quaternary coding trees corresponding to the packet success probabilities of different nodes in the wireless ad-hoc network.



next: #1'135'479

1s 907ms 971us 755ns 876ps

In: DsdvNetwork.host[58].wlan[0].radio (Ieee80211ScalarRadio, id=3651)

At: 1.907971776318s (now+0.000000020442s)

```
INFO (Dcf)DsdvNetwork.host[33].wlan[0].mac.dcf:Processing received frame Hello as recipient.
** Event #1135476  t=1.907971755876  DsdvNetwork.host[33].wlan[0].llc (Ieee80211LlcLpd, id=2123)  on Hello (inet::P
INFO:Received (inet::Packet)Hello from lower layer.
** Event #1135477  t=1.907971755876  DsdvNetwork.host[33].ipv4.ip (Ipv4, id=2160)  on Hello (inet::Packet, id=1573031)
INFO:Received (inet::Packet)Hello from network.
DETAIL:Received datagram `' with dest=255.255.255.255
INFO:Broadcast received
INFO:Delivering (inet::Packet)Hello (36 B) [[inet::physicallayer::Ieee80211DsssPhyHeader, length = 6 B | inet::ieee80211::Ieee80211DataHeader
INFO:Passing up to protocol manet(39)
** Event #1135478  t=1.907971755876  DsdvNetwork.host[33].dsdv (Dsdv, id=2118)  on Hello (inet::Packet, id=1573031)
```

Figure 3

Screenshot of simulation scenario in OMNeT++ for the pro-posed DSDV routing scheme.

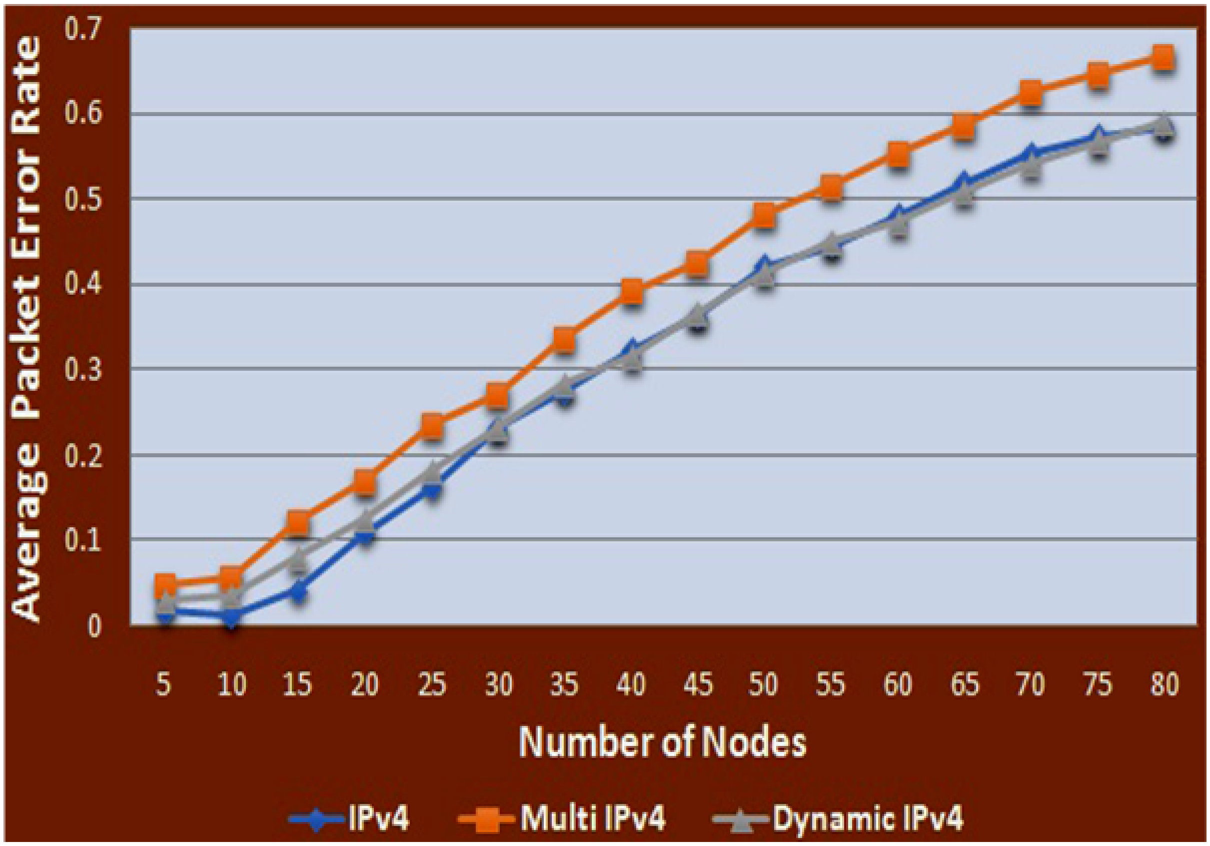


Figure 4

Evolution of average packet error rate for different IP protocols versus the number of nodes in the network.

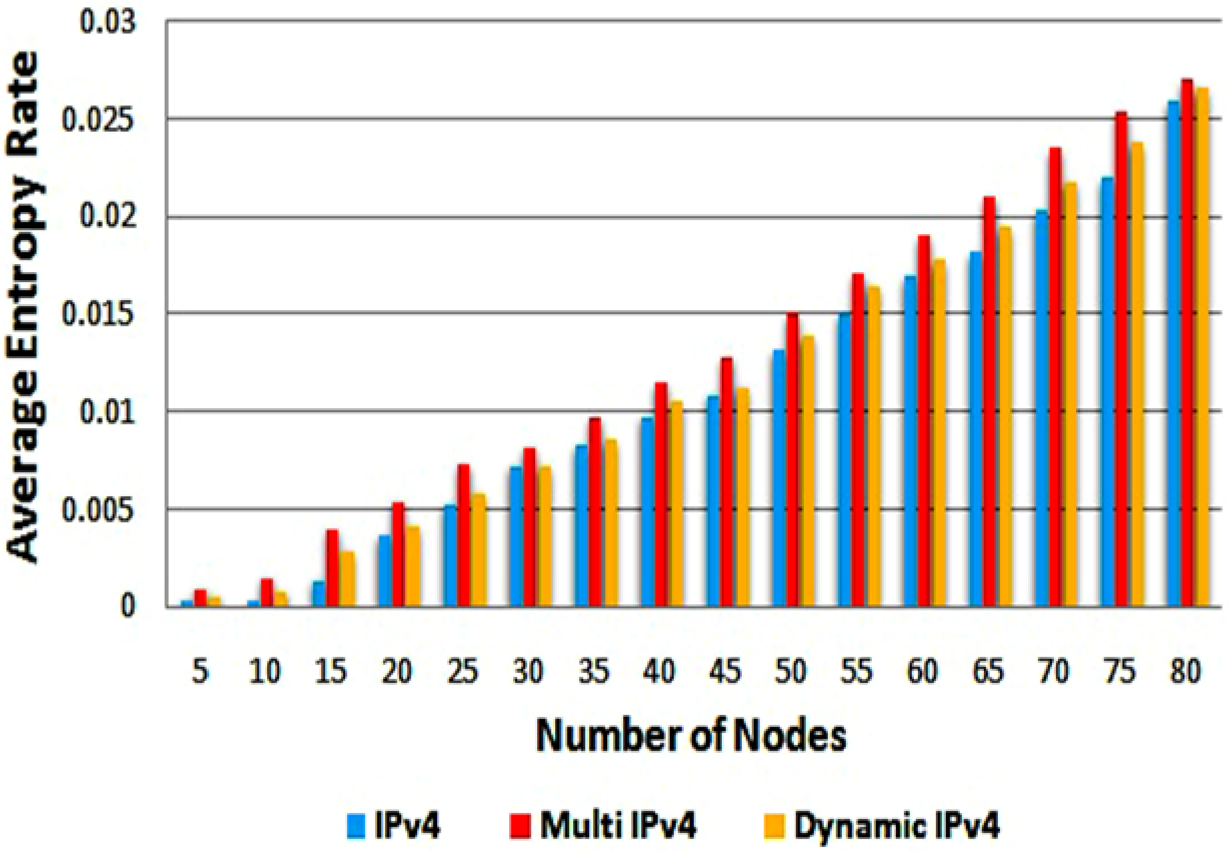


Figure 5

Plot of the average entropy rate for different IP protocols versus the number of nodes in the network.

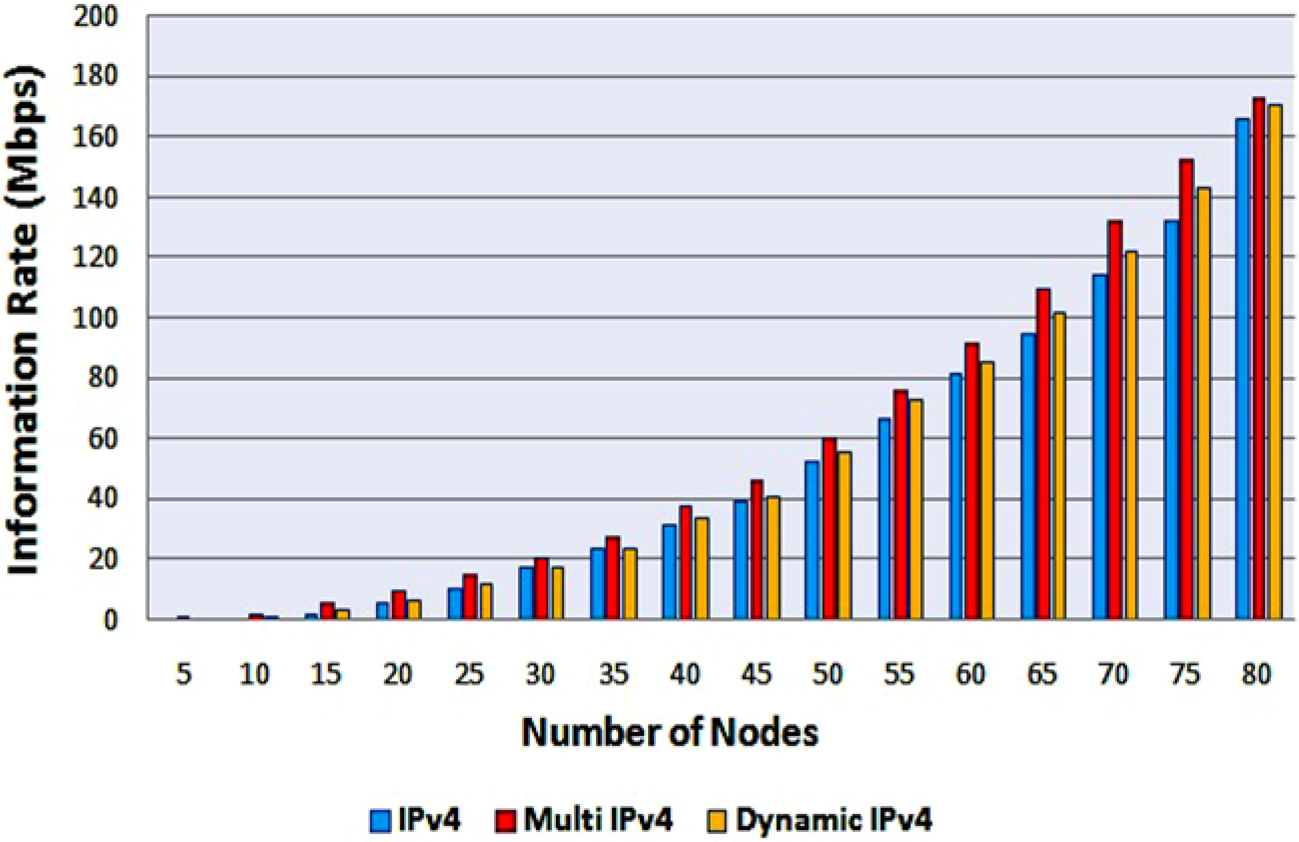


Figure 6

Information rate attained with different IP protocols versus the number of nodes in the network.

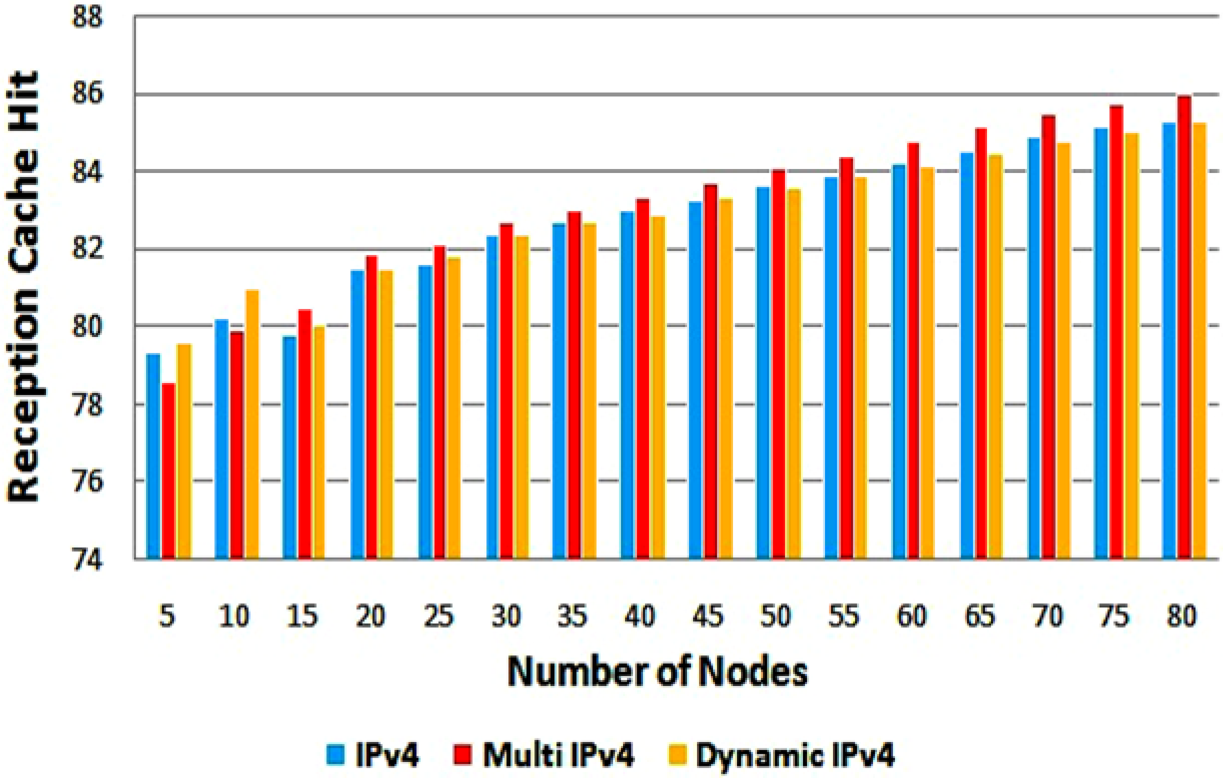


Figure 7

Reception cache hit retrieved using different IP protocols ver-sus the number of nodes in the network.

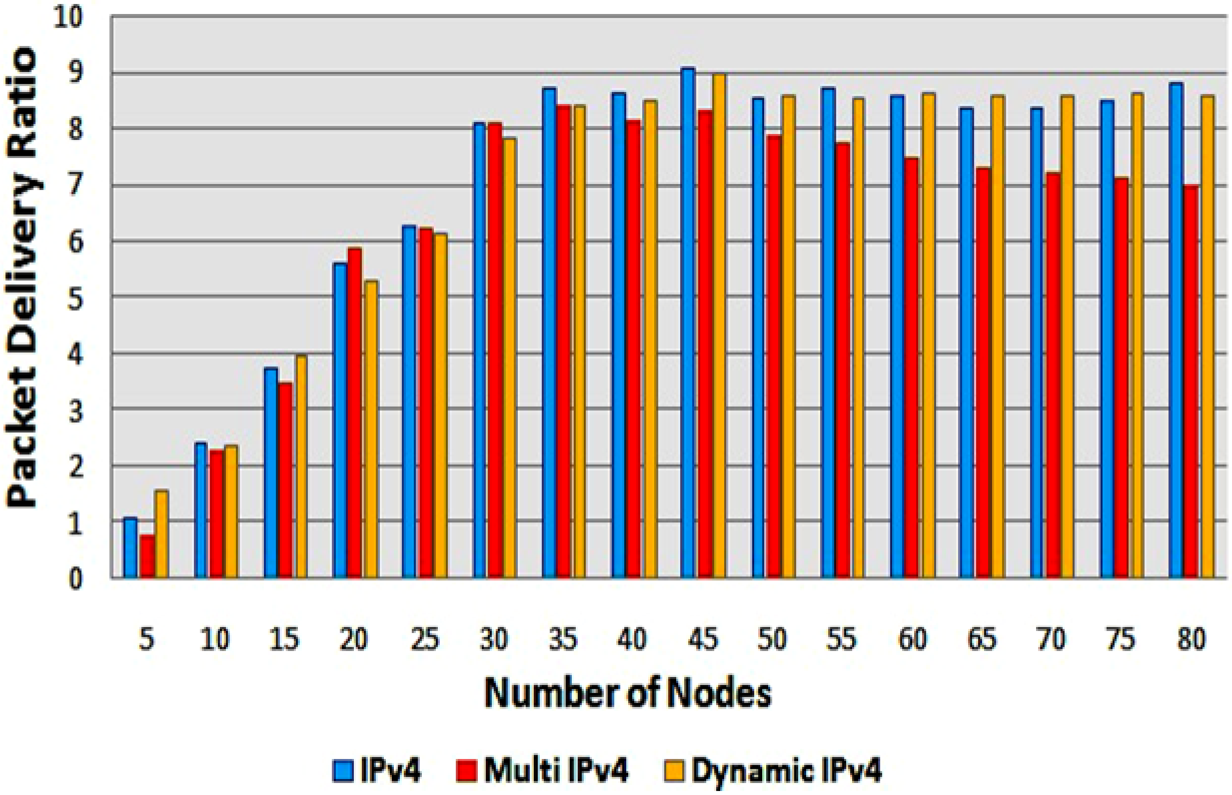


Figure 8

Packet delivery ratio for different IP protocols versus the num-ber of nodes in the network.

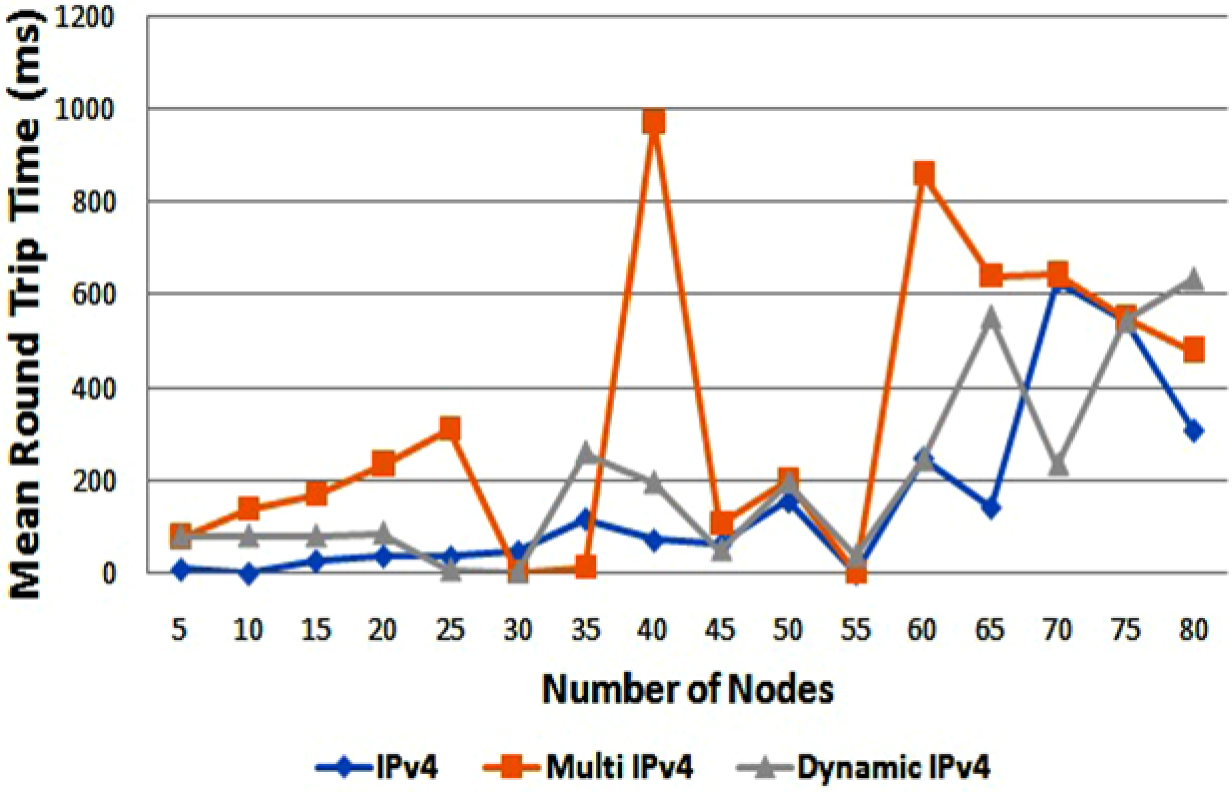


Figure 9

Mean round trip delay experienced with different IP protocol implementations versus the number of nodes in the network.

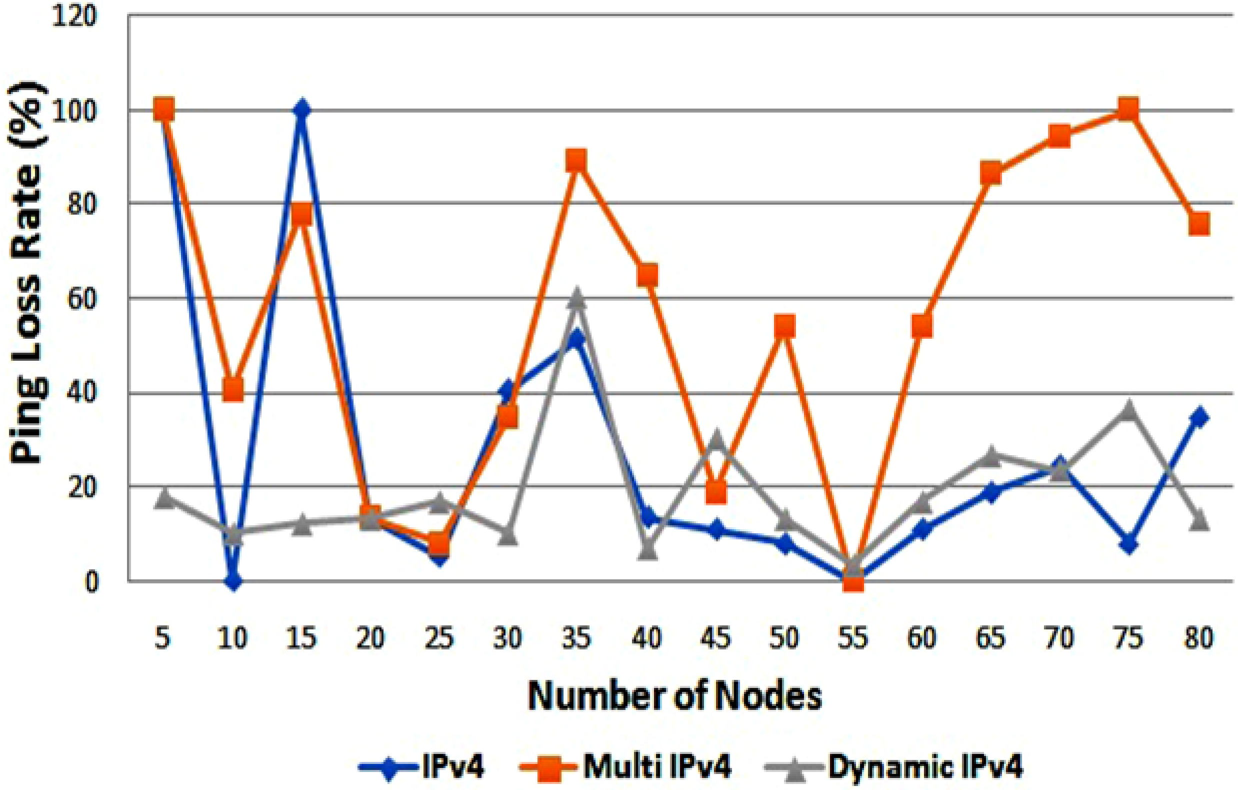


Figure 10

Evolution of ping loss rate encountered with disparate IP pro-tocols versus the number of nodes in the network.

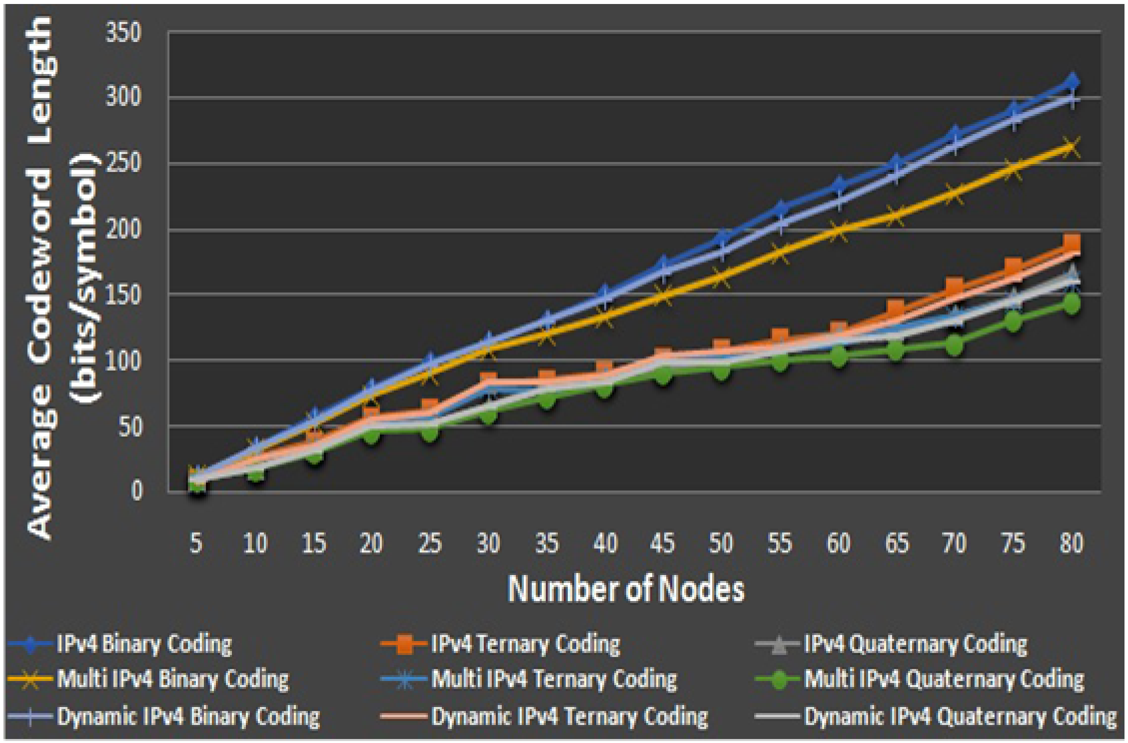


Figure 11

Average codeword length for binary, ternary and quaternary coding schemes executed for different IP protocol types vary-ing with the network size.

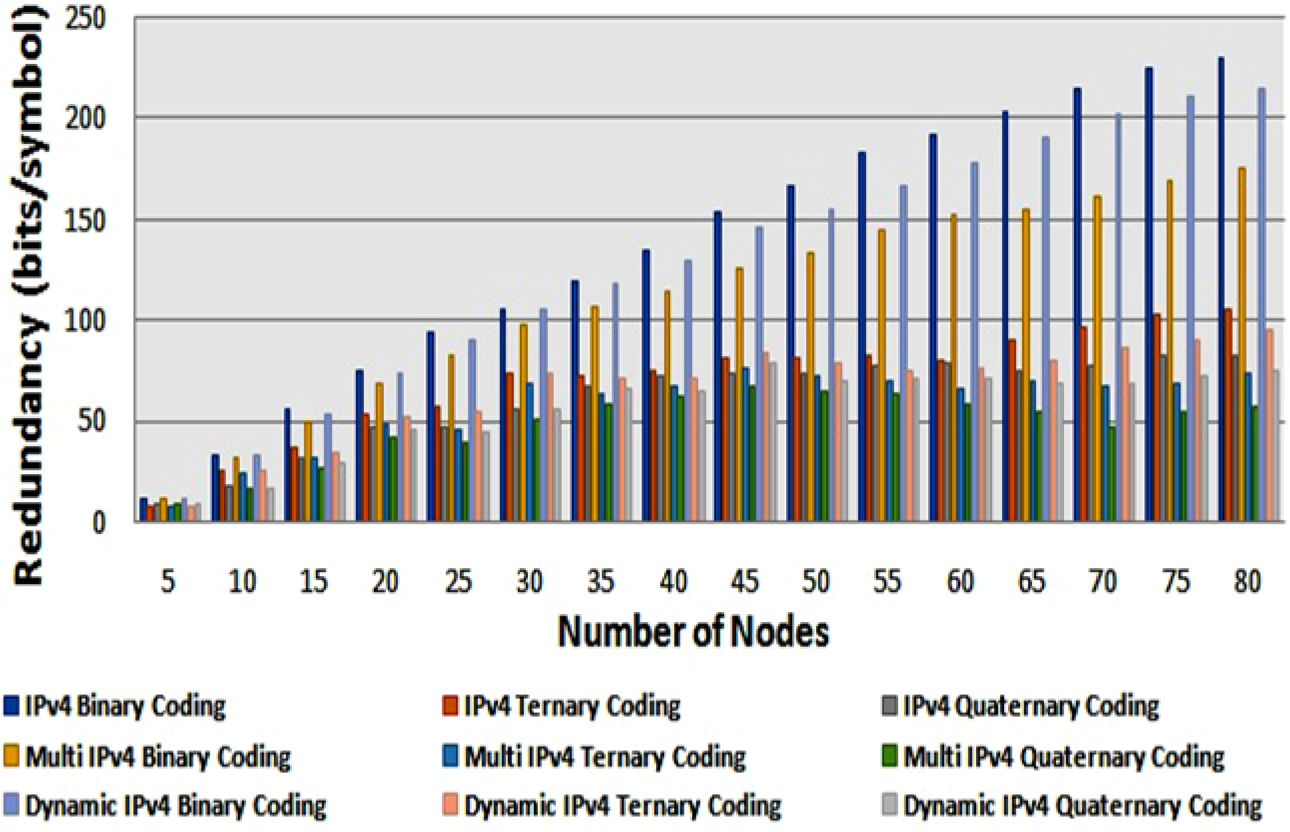


Figure 12

Redundancy for binary, ternary and quaternary coding tech-niques executed for different IP protocol types varying with the network size.

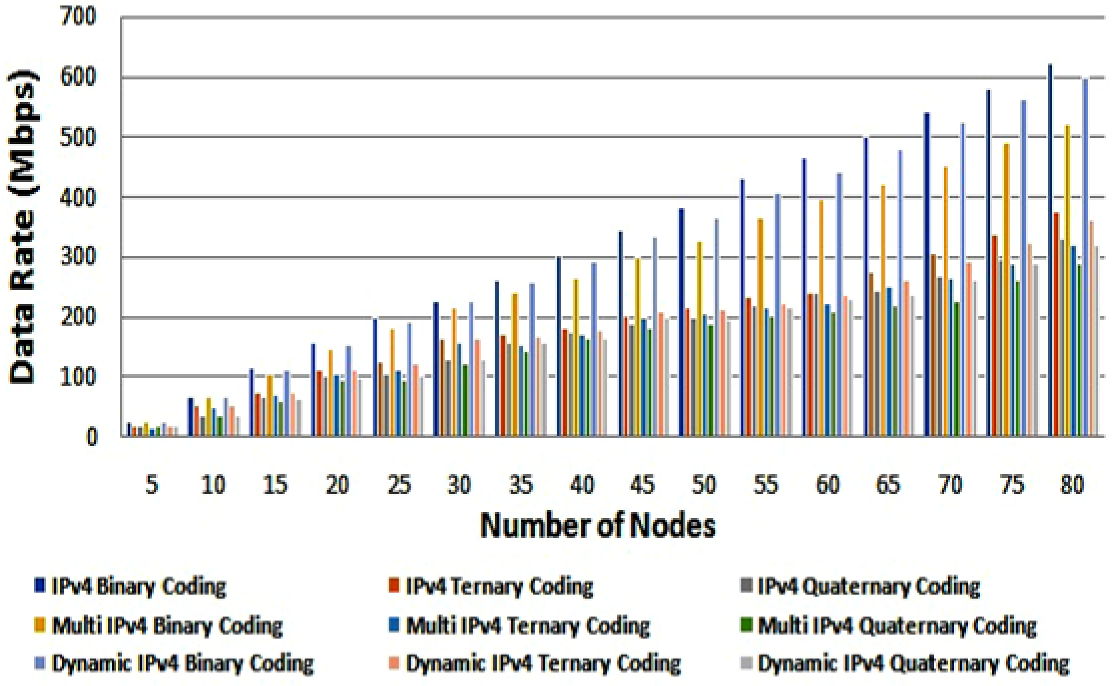


Figure 13

Achievable data rates for binary, ternary and quaternary Huff-man coding applied to different IP protocol types varying with the network size.

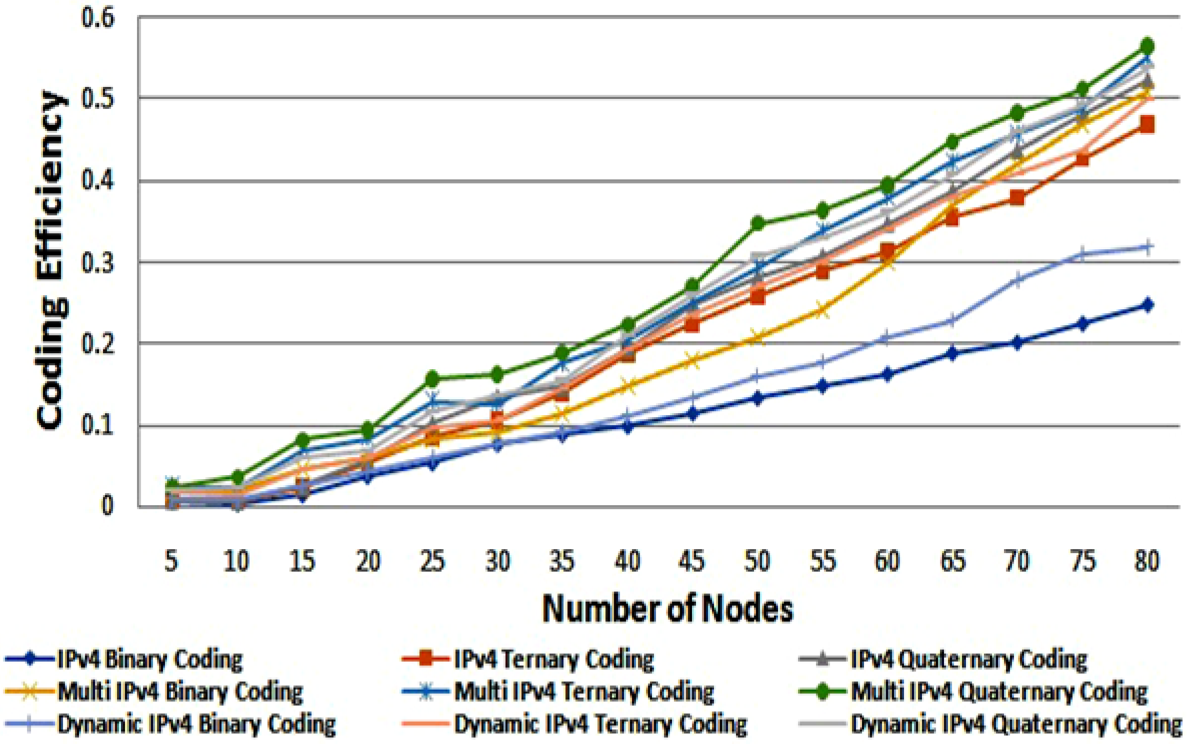


Figure 14

Coding efficiency for binary, ternary and quaternary coding schemes executed for distinct IP protocol types varying with the network size.