Chapter 5
Performance Evaluation

5.1 Methodology

Extensive simulations are conducted for the proposed work. Network Simulator 3 (NS3) is used for network simulation, while Simulation of Urban Mobility (SUMO) is used to generate mobility traces on a real road network [32], [33]. NS3 and SUMO are both open-source software widely used in research and academia. Vehicle mobility traces with realistic road topology, vehicle density, and speed are generated by the use of SUMO. This NS3-compatible vehicular trace file is called in NS3 to add WAVE-based wireless communication capabilities. Network functionalities and applications are installed on all moving traces of vehicles and communication statistics are recorded. Figure-5.1 represent overall simulation set-up and process-flow.

Different mobility patterns and vehicle densities are considered for evaluating performance of proposed work. For comparison, two existing protocols, flooding and slotted 1-persistent broadcast, are recreated in the same environment. In the flooding strategy, every vehicle, irrespective of its location and requirements, broadcasts all received packets for the first time. S1PD is a representative delay-based protocol used for reference. In S1PD, every potential relay candidate elects one slot depending on its separation from the sender. Slots are converted to delay, prioritizing the farthest vehicle to rebroadcast the received packet.

5.2 Performance Metrics

In order to measure the performance of proposed approaches, three performance metrics — coverage, mean delay, and number of hops — are defined below. These

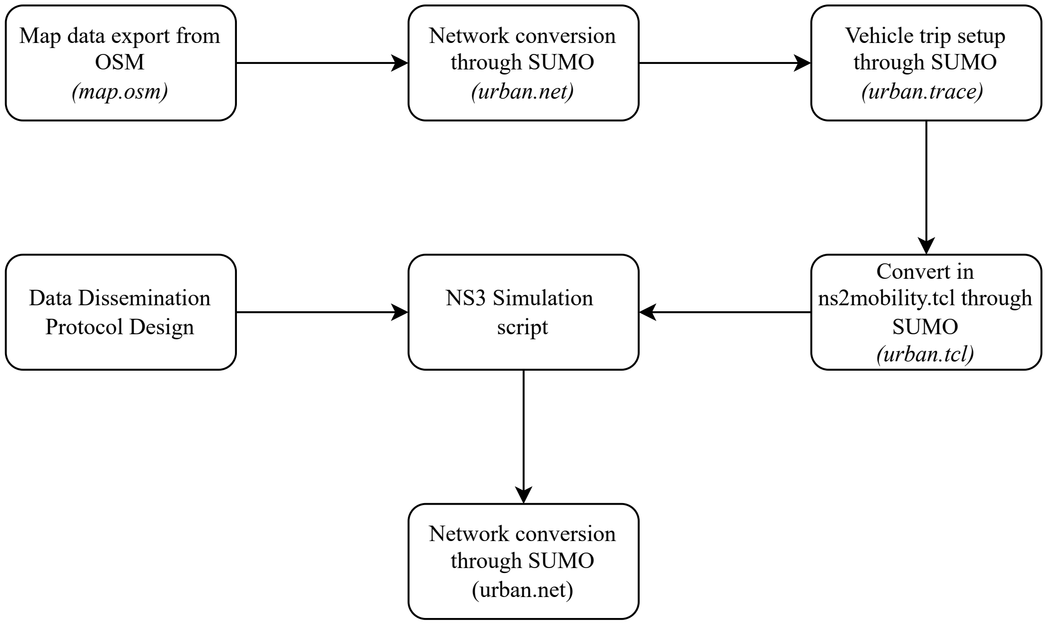

Figure 5.1: Simulation work-flow

three metrics collectively define the performance of message dissemination protocols [62].

- **Coverage:** It represents the overall reachability of the alert message within the considered network. Reliability and dependability of safety message dissemination are ensured by high coverage. The coverage percentage is calculated by dividing the percentage of Alert receiving vehicles by the total number of vehicles.

$$Coverage(\%) = \frac{Number\ of\ vehicles\ who\ received\ alert}{Total\ number\ of\ vehicles} \tag{5.1}$$

- **Delay:** It represents the average time an alert message takes to reach all vehicles located within the boundaries of the area of interest. Safety message broadcasting is a time-sensitive task, and a large delay reduces the applicability of the protocol for the envisioned application. Measuring the average time, an alert message takes to reach a boundary gives the delay metric.

$$Delay\ (mean) = \frac{1}{N\_recv} \sum_{v=1}^{N\_recv} Recev\_time - Gen\_time \tag{5.2}$$

- **Hop-count:** It is the measurement of the average number of rebroadcasts a message requires to reach the boundary of measurement. Every time a message is rebroadcast, a hop count variable is incremented to reveal the per-message hop count.

$$Hop\text{-}count = \frac{1}{N\_recv} \sum_{v=1}^{N\_recv} Required\_broadcast \tag{5.3}$$

5.3 Simulation Scenarios

5.3.1 Highway topology

A 5 km long 3-lane highway is selected for simulation. The road network can be imported from OpenStreetMap into sumo or Highway and grid topolologies can be easily created through netedit utility of sumo. SUMO import road networks and create vehicles' mobility over them.

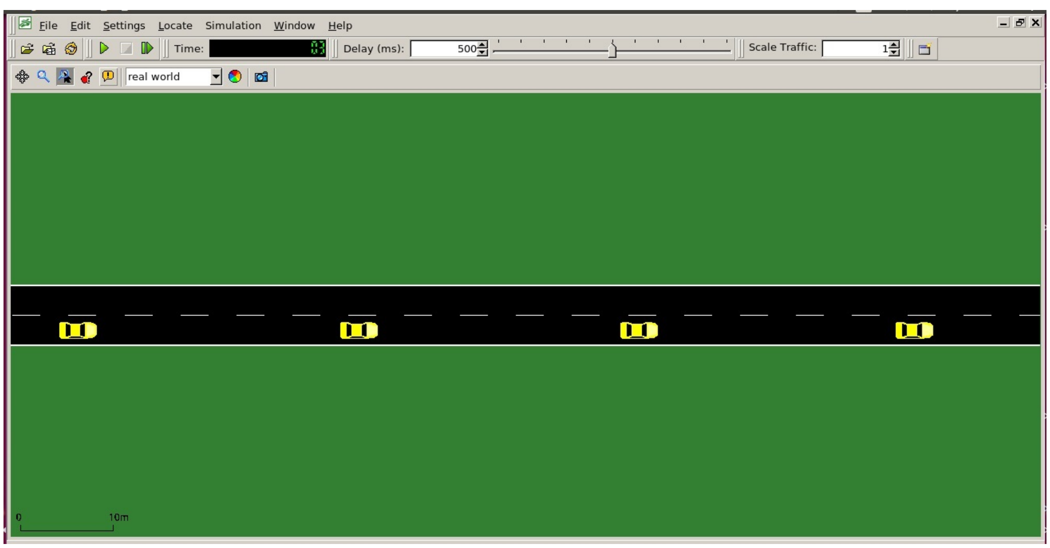

Figure 5.2: Road network and vehicle mobility in SUMO

The figure 5.2 shows the imported road network and its corresponding vehicle traffic. Physical and MAC layer parameters are configured in NS3 to implement wireless connectivity among vehicles. The default transmission range is 300 m; and the data rate for beacon and alert messages is 6 Mbps. Vehicle densities are varied from 100 to 500, and speeds are varied from 50 to 100 km/h. A list of all simulation parameters is provided in Table 5.1

Parameters	**Value**
Simulation area	5 km (3-lane Highway) $2.5 \times 2.5\ km^2$ (Urban area)
Total Simulation Time	50 sec
Vehicle density	100 - 600
Velocity	5 m/sec - 20 m/sec
Transmission Range	300 m
Packet size	200 bytes
Data Rate	6 Mb/s
MAC layer & Physical layer	802.11p
Propagation model	Nakagami

Table 5.1: Simulation Parameters

Figure 5.3 shows the pictorial representation of the safety application scenario. A crash site is in the middle of the highway. To avoid randomness because of vehicle insertion and exit, measurement statistics were calculated over an area of interest (AoI) of 3 km around the center point.

5.3.2 Urban topology

A $2.5 \times 2.5\ km^2$ *OpenStreetMap* dataset from Chandigarh, India, is imported into SUMO to generate real road networks.Simulations of vehicle traffic and mobility traces are generated by SUMO over those road networks. Figure 5.4 shows the imported *OpenStreetMap* and its corresponding road networks extracted in figure 5.5 through use of SUMO tools. The IEEE 802.11p protocol is integrated into NS3 to simulate vehicular networks. The data rate is set at 6 Mbit/sec at the

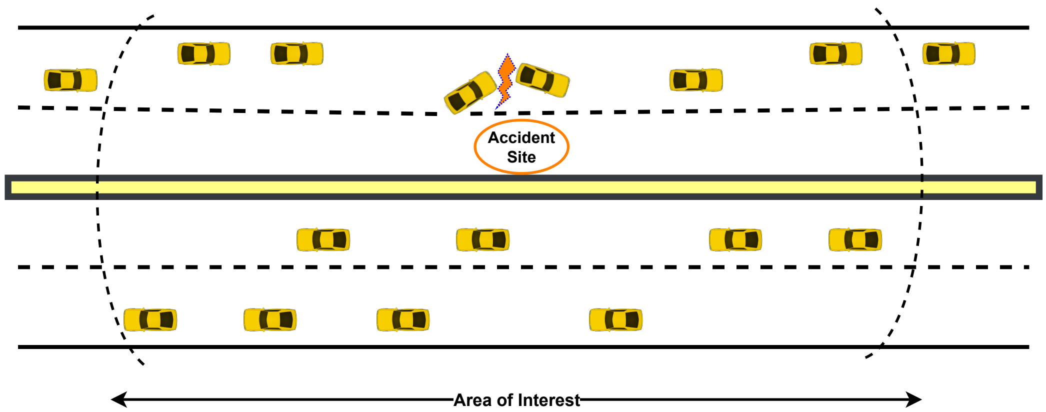

Figure 5.3: Application scenario

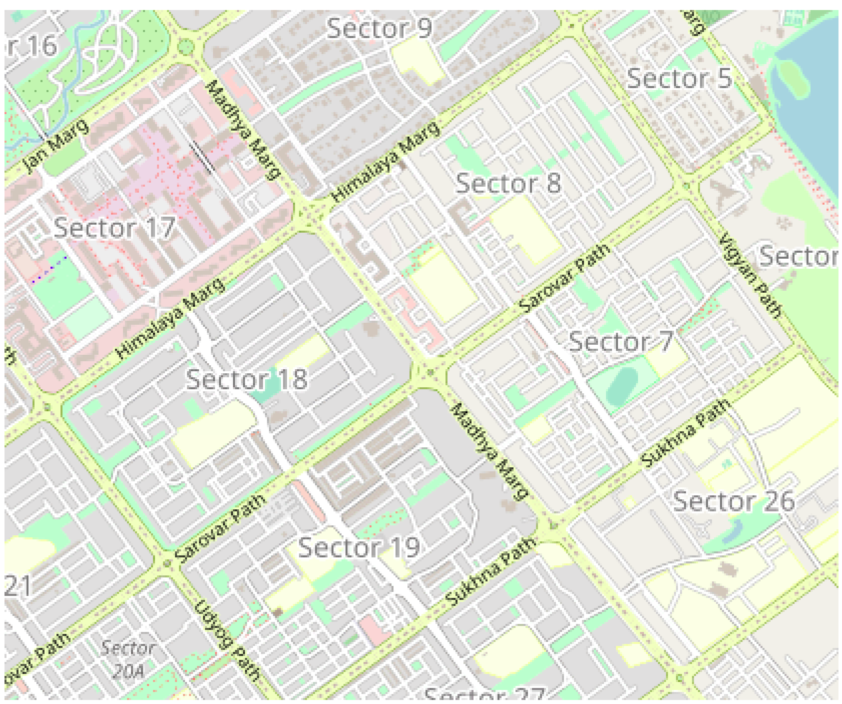

Figure 5.4: OpenstreetMap of chandigarh

Figure 5.5: OSM map converted in road network

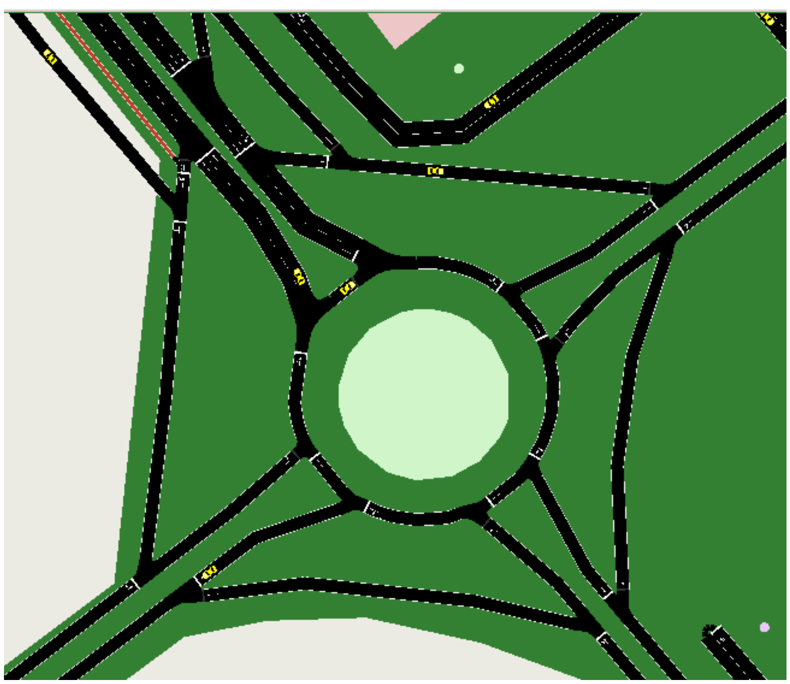

Figure 5.6: SUMO generated Vehicular Movement

MAC layer. The transmission power is set to provide roughly 300 meters of range. In the chosen area, the vehicle density ranges from 100 to 600. Figure 5.6 depicts simulated vehicular movements on a real-world road network. Table-5.1 lists all of the parameters used in simulation.

5.4 Simulation Results

Figure 5.7: Measurement boundary

This section discusses the performance improvements achieved by the proposed protocols. Validation of improvements is done by comparing the findings with *BFP* protocol and the conventional slotted delay based *S1PD* protocol. A road boundry at 1.5 km from the crash cite is used as a reference measurement region in the highway scenario. While in the urban scenario, a circular region of 3 km diameter with crash cite at center is taken as a reference measurement region. The number of hops and the mean delay parameters are measured around the boundary of that region. Figure 5.3 & 5.7 shows the measurement region over which statistics of "hops" and "mean delay" are calculated.

5.4.1 Simulation Results Over the Highway

Figure 5.8, 5.9 and 5.10 shows the performance statistics of highway topology. Figure 5.8 shows the net coverage of alert messages in the considered network. It represents coverage statistics with different node densities in the network. It shows that the ERDB protocol provides higher coverage compared to S1PD. In the flooding protocol, every node will retransmit the alert, so coverage is higher in flooding but at the cost of excessive broadcasting of alert messages. ERDB provides comparable coverage with reduced traffic. The coverage performance of the ARB protocol is marginally higher than the S1PD protocol. At higher densities, ARB protocol coverage degrades due to its excessive message collisions due to a shorter delay. After a node density of 400 ARB, coverage decreased below S1PD. The collected coverage statistics are presented in table 5.2.

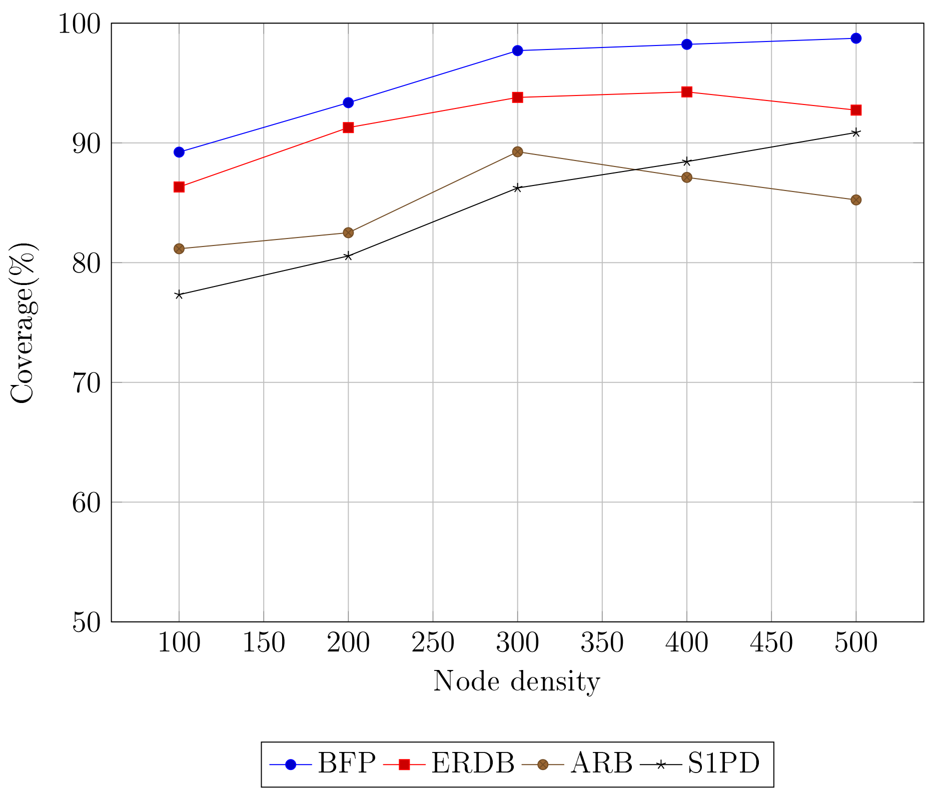

Figure 5.8: Coverage (%) Vs Node Density

Figure 5.9 shows the average delay versus node density plot. Safety alert

Nodes	Flooding	ERDB	ARB	S1PD
100	89.23	86.32	81.16	77.33
200	93.36	91.28	82.5	80.56
300	97.71	93.8	89.26	86.24
400	98.23	94.26	87.12	88.44
500	98.74	92.74	85.24	90.87

Table 5.2: Coverage (%) (Highway topology)

message transmission is a time-sensitive task. So a good protocol must provide a minimal delay in broadcasting the message on the network. It is evident that, due to the adaptiveness employed in broadcast delay, ERDB and ARB both offer the best delay performance compared to the S1PD protocol. The delay performance of ERDB is more stable and uniform compared to ARB. ARB has a lower latency at moderate to low vehicle densities, but performance degrades above 400 nodes.

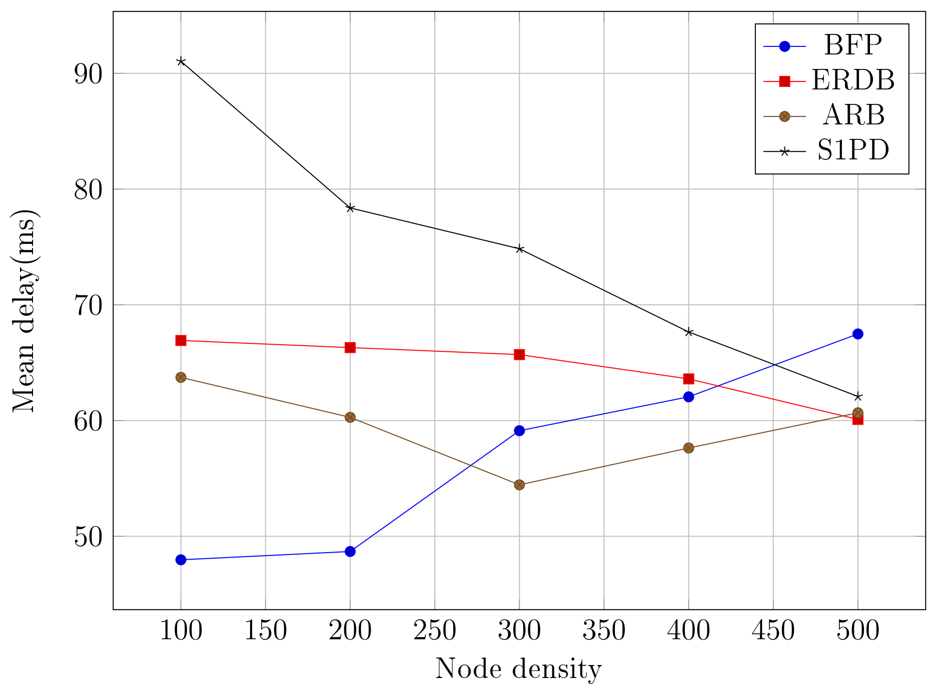

Figure 5.9: Mean delay time Vs Node Density

Figure 5.10 shows the plot of hops versus node density. It represents the average number of hops an alert message will require to reach the measurement

Nodes	Flooding	ERDB	ARB	S1PD
100	47.96	66.91	63.72	91.04
200	48.68	66.30	60.27	78.37
300	59.12	65.69	54.44	74.84
400	62.05	63.60	57.63	67.65
500	67.48	60.09	60.66	62.08

Table 5.3: Mean delay (ms) (Highway topology)

point. S1PD is the longest-distance protocol, with fewer hops than ARB and ERDB. Due to its strict waiting time formula, S1PD has a lower delay performance despite its longer one-hop distance. But as node density increases, ERDB performs comparably to S1PD.

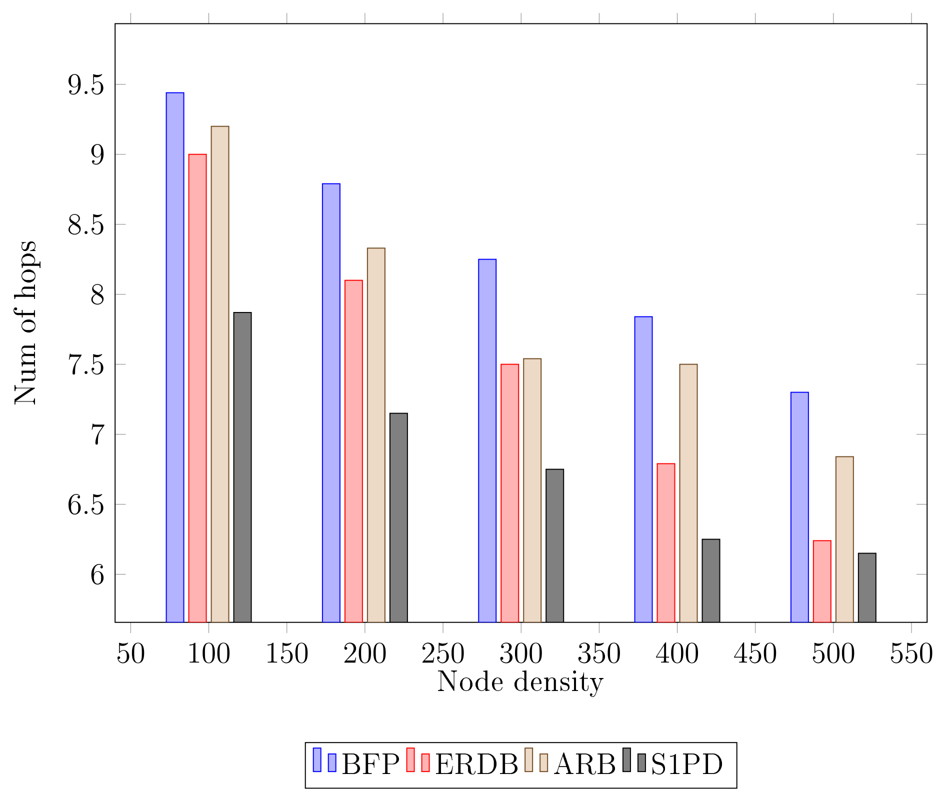

Figure 5.10: Number of Hops Vs Node Density

In a flooding-based broadcast, an alert message will need a high number of hops to reach its destination. The recorded values of coverage, mean delay, and average number of hops are presented in tabular form in table 5.2, 5.3 and 5.4.

Nodes	Flooding	ERDB	ARB	S1PD
100	9.44	9.2	9	7.87
200	8.79	8.33	8.1	7.15
300	8.25	7.54	7.5	6.75
400	7.84	7.5	6.79	6.25
500	7.3	6.84	6.24	6.15

Table 5.4: Hop-count (Mean) (Highway topology)

5.4.2 Simulation Results Over the Urban Area

This section evaluates the performance of the ARB and ERDB protocols in complex urban scenarios. Compared to highways, vehicular communication will face more challenges in urban topology. Urban areas have different road networks, high speed variations, and multi-directional vehicular movements.

Figure 5.11 shows the coverage percentage for all four discussed methods. A good alert dissemination protocol must offer a high level of coverage, even in dense urban situations. Multi-hop data dissemination protocols have a trade-off between delay efficiency and reliability. Flooding and ARB both perform poorly in high-density situations due to accessive packet collisions in the network. Flooding does not provide a resolution to reduce packet drops. The similar coverage of ERDB with S1PD confirms that the delay improvement attempts in ERDB do not penalize the net reachability count in the network.

Figure 5.12 shows a graph of mean delay versus node density. It is apparently visible that the delay continuously reduces as node density increases. The main reason for this behavior is that relay nodes will be close to the transmission region's boundary at higher node densities. As a result, the wait time before broadcasting is reduced.

S1PD and ERDB are stable protocols that reduce delay as node density increases. In the case of flooding, the delay is initially very low but rapidly increases

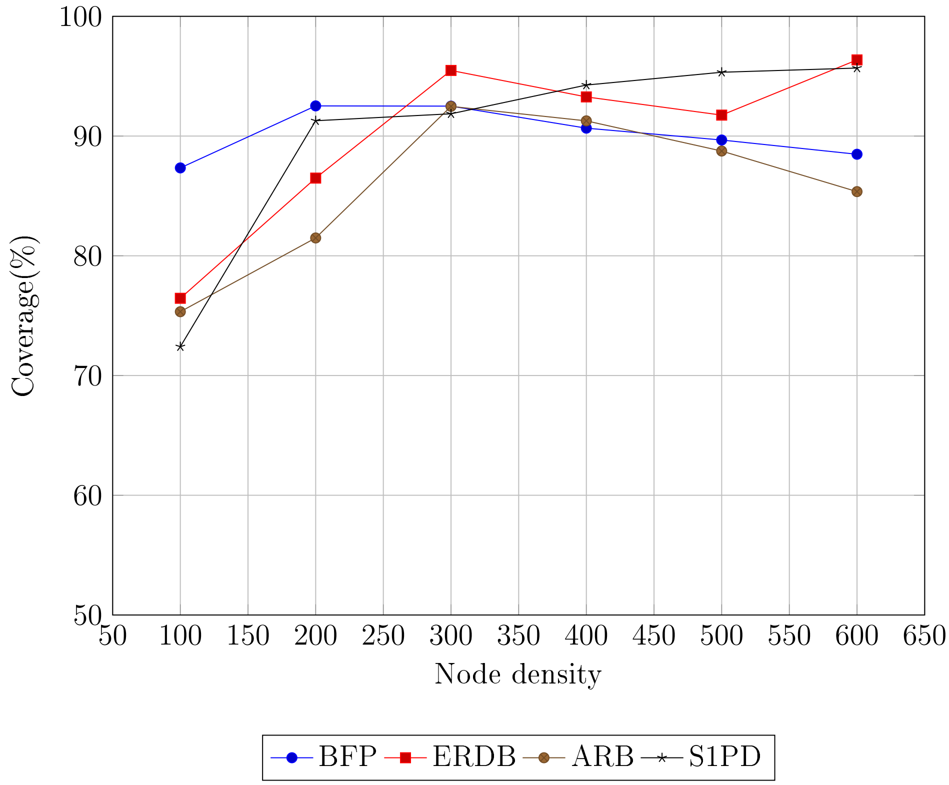

Figure 5.11: Coverage (%) Vs Node Density

Nodes	Flooding	ERDB	ARB	S1PD
100	87.34	76.45	75.33	72.41
200	92.52	86.49	81.49	91.28
300	92.50	95.48	92.48	91.86
400	90.66	93.27	91.27	94.26
500	89.67	91.75	86.75	95.33
600	88.48	96.36	82.36	95.68

Table 5.5: Coverage (%) (Urban topology)

as the density increases. As observed in highway topology, ARB offers the lowest delay at low to moderate vehicle densities. But as density increases, S1PD and ERDB both start outperforming ARB.

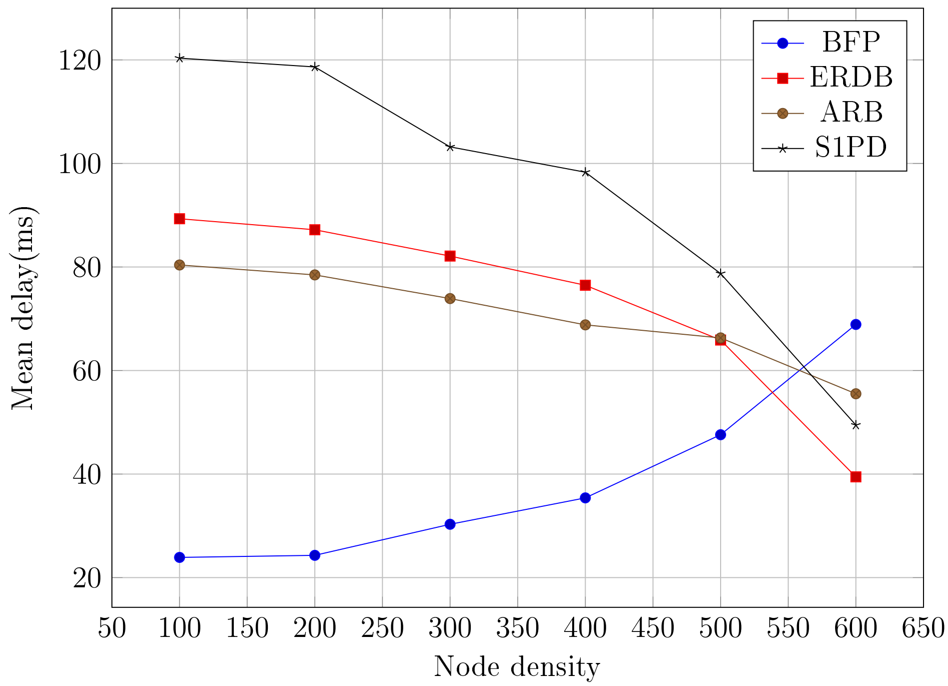

Figure 5.12: Mean delay time Vs Node Density

Nodes	Flooding	ERDB	ARB	S1PD
100	23.90	89.32	80.39	120.34
200	24.30	87.19	78.47	118.64
300	30.30	82.11	73.90	103.20
400	35.40	76.47	68.82	98.31
500	47.60	65.89	66.30	78.73
600	68.90	39.46	55.51	49.46

Table 5.6: Mean Delay (ms) (Urban topology)

Fig-7 presents total alert messages sent in the network by vehicles with respect to node density. As node density increases within the fixed geographical area, more nodes are reachable with fewer transmissions. The plot confirms that BFP generates high redundancy in the network by forwarding many alert messages in the network. It creates a broadcast storm problem in the network and net reachability gets penalized.

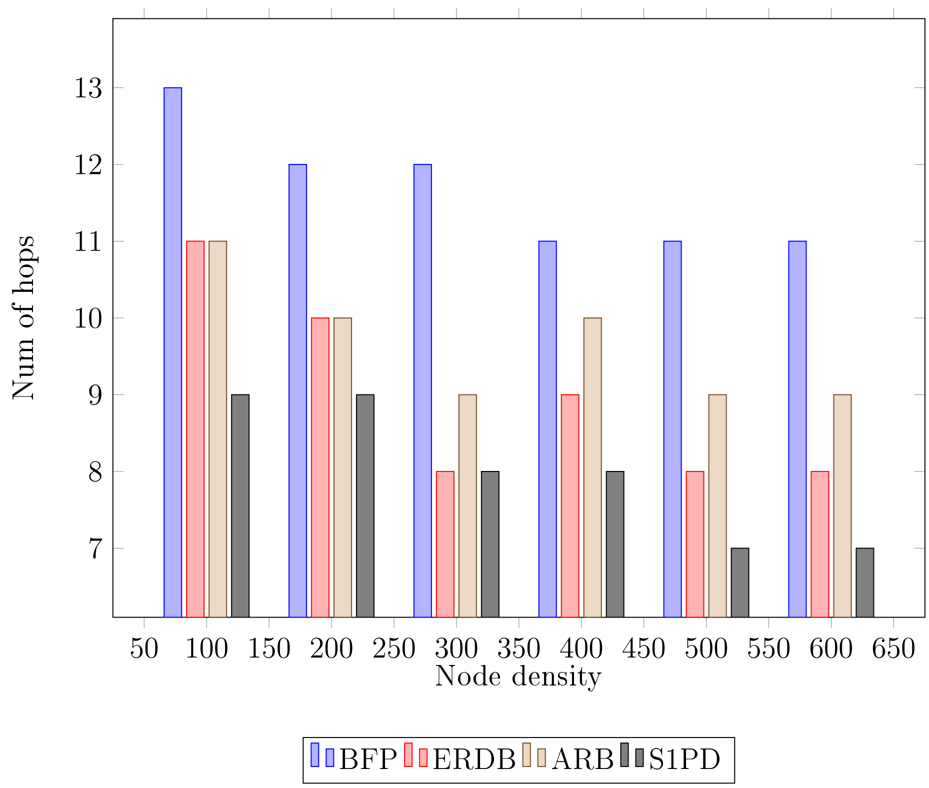

Figure 5.13: Number of Hops Vs Node Density

Figure 5.13 presents the average number of hops required to reach the alert message and reach the measurement boundary. Being a furthest distance protocol, S1PD always use less number of hops to reach boundery. But the efficient design of ERDB results in the second-lowest hop count performance. The hop-count of BFP will always be higher due to frequent broadcasting.

Table 5.5, 5.6 and 5.7 show the measured statistics of the urban vehicular network.

Figure 5.14 presents the total alert messages sent in the network by vehicles with respect to node density in urban vehicular networks. In a vehicular ad hoc network, up to a limit, with an increase in node density within the fixed geographical area, the network becomes well connected and more nodes are reachable with fewer transmissions. At very high densities, a large number of nodes start

Nodes	Flooding	ERDB	ARB	S1PD
100	13	11	11	9
200	12	10	10	9
300	12	9	8	8
400	11	10	9	8
500	11	8	8	7
600	11	8	8	7

Table 5.7: Hop-count (Urban topology)

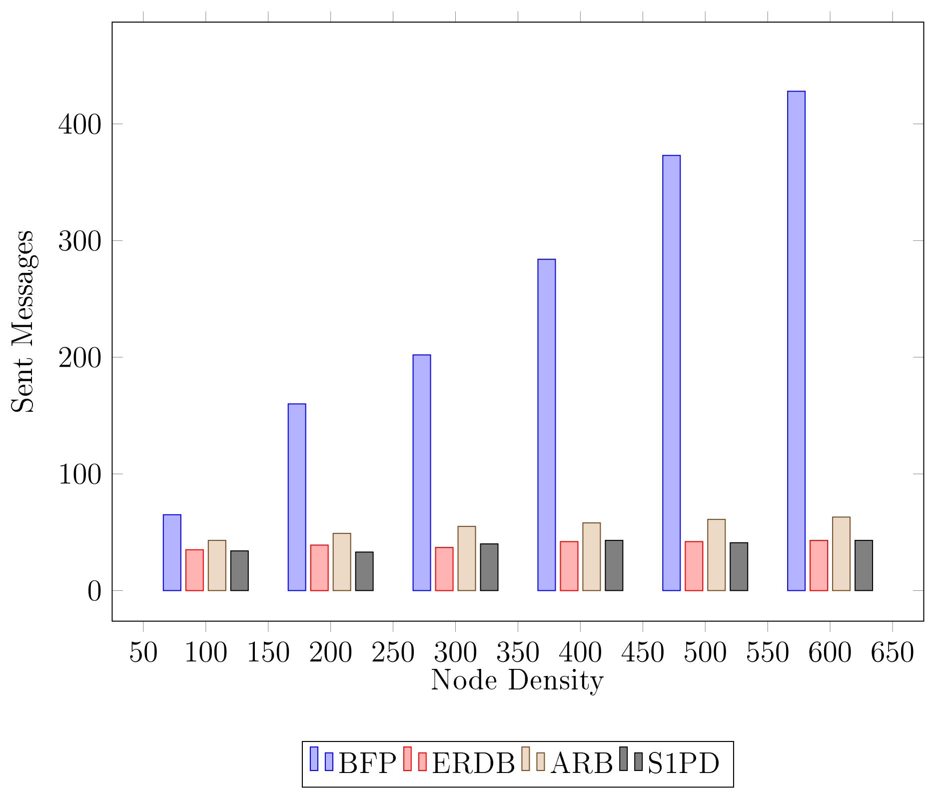

Figure 5.14: Total sent messages Vs Node Density

Nodes	Flooding	ERDB	ARB	S1PD
100	65	35	43	34
200	160	39	49	33
300	202	37	55	40
400	284	42	58	43
500	373	42	61	41
600	428	43	63	43

Table 5.8: Total Sent Messages (Urban topology)

competing with each other for relaying the message, and performance starts degrading. The plot confirms that S1PD, ARB, and ERDB are successfully reducing total sent messages as compared to flooding. Flooding generates high redundancy in the network by forwarding a large number of alert messages. A previously described flooding-based scheme does not attempt to reduce redundant transmissions and simply broadcasts every single new message. In multi-hop communication, flooding results in a broadcast storm problem, and performance is penalized heavily.

5.5 Summary

We summarize performance outcomes and research findings in this section.In figures 5.6–5.8, we show the performance results of the S1PD, ARB, and ERDB protocols over a 5-kilometer highway scenario. In figures 5.9-5.11, we presented the performance results of the S1PD, ARB, and ERDB protocols over real road networks of chandigarh city with area of 2.5× 2.5 kilometers (urban scenario).

Two proposed protocols, ARB and ERDB, are compared against S1PD and flooding-based protocols. Each measurement in the plot is the average of 10 simulations with 90% confidence interval. From studying the findings, we summarize the following:

- Adaptive delay based protocols perform better than fixed delay based protocols.

- ERDB is a adaptive multi-critera protocol perform beter at higher node density.
- ARB is a fast and efficient protocol but performs poorly at high node densities.
- The drawbacks of ARB in terms of reliability and scalability are overcome by the ERDB protocol.
- Both the ARB and ERDB protocols provide comparable network coverage to S1PD.