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Optimized Buffer Management Policy for Tailoring DTN Routing Protocols to IoT

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Abstract: Delay Tolerant Network (DTN) represents a category of network architectures tailored to challenging network environments. Its primary focus is on addressing network discontinuity, alongside tackling issues like resource constraints and network heterogeneity. Over the past few decades, DTNs have garnered attention as an alternative or complement to existing routing protocols, with a special emphasis on supporting emerging network-based applications that demand enhanced delay tolerance, fault resilience, and flexibility. Among these applications, the Internet of Things (IoT) stands out as a significant domain. This paper provides a brief overview of the commonalities and areas where DTN solutions converge within IoT applications. To enhance delay-tolerant routing in IoT, this work introduces a DTN-based routing protocol known as the Optimised Spray and Wait Protocol (OSnW). This protocol is proposed as a viable alternative for IoT applications with limited buffer resources. Comparative evaluations against three widely used protocols, Epidemic, Spray and Wait, and ProPHET, reveal that the proposed OSnW protocol excels in several key evaluation metrics. The overarching goal of this research is to offer a solution that empowers delay-tolerant routing within the realm of IoT.

Keywords: *Delay Tolerant Networks, Internet of Things, Routing; Spray and Wait, ProPHET*

1. Introduction

As the Internet of Things (IoT) continues to infiltrate various real-life applications, the need for a supporting infrastructure becomes increasingly apparent. The emergence of more intricate and advanced applications necessitates a network and communication system that is both reliable and consistent. Compounding this challenge is the rapid spread of digitization, which often outpaces the growth of physical infrastructure. This issue presents itself in both sparsely populated rural areas and densely populated urban centers. To enable the widespread adoption of IoT-based services, particularly in areas lacking comprehensive technical infrastructure, alternative solutions are required. Delay Tolerant Networking (DTN) can bridge this gap by offering alternative and hybrid solutions to address this challenge. DTN solutions are purpose-built for environments with limited or unreliable infrastructure, making them valuable for extending IoT services in such conditions [1,2].

1.1. Abbreviations and Acronyms

In most IoT applications, data is collected through resource-constrained sensors, posing a significant challenge in processing a vast amount of real-time, and often multimedia, data from diverse sensor types while maintaining dependable communication. The critical requirement is that the network optimally utilizes its resources while ensuring a consistent Quality of Service. Sensor-based IoT networks face substantial concerns, such as the inability to establish permanent connections due to limited available bandwidth and constraints in processing power and memory, making it challenging to maintain continuous state information for each connection. The mobility of nodes adds an additional layer of complexity. Research indicates that Delay Tolerant solutions can enhance the overall network performance. Moreover, IoT applications that demand multicast services could benefit from DTNs, as they demonstrate excellent performance in disseminating multicast data to large groups of heterogeneous nodes.

Most DTN-enabled IoT solutions revolve around decentralizing the routing process and replacing continuous connectivity with "opportunistic" connectivity. Opportunistic behavior implies that data transmission times and neighbor selections are determined opportunistically, often when chance encounters occur. The success of these decision algorithms depends on the availability and accuracy of prior knowledge (predictions), which may not always be accessible. Research has shown that striving for absolute optimization while considering the required resources and stability demands an unrealistic amount of computation. Consequently, practical hybrid algorithms are proposed [3]. Most prevalent algorithms fall under the category of the store-carry-forward mechanism. Nodes, whether stationary or mobile, are grouped into different clusters, and they carry and forward messages across the network to their intended destinations.

The most widespread hybrid approaches involve incorporating a DTN-based layer, often referred to as the Bundle layer, into the existing TCP/IP protocol architecture. These adaptations do not entirely mitigate the challenges of IoT applications but strike a reasonable balance between performance and resource utilization. This research delves into these aspects and presents an innovative alternative.

The main contributions of this paper are the following: • The paper identifies the similarities and areas of convergence in the use of DTN solutions in IoT applications

• A brief survey of existing DTN routing solutions is performed with a focus on protocols adapted for IoT applications.

• The design and implementation of OSNW protocol, a Buffer-adapted variation of the "Spray and Wait" protocol based on the combination of the benefits of the DTN routing strategies;

• The proposed OSNW protocol is compared to the existing DTN routing solutions for IoT;

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The remainder of this paper is organized according to the following plan: In Section 2, the concept of Delay Tolerant Networks, the interrelationship between IoT and DTN, as well as existing hybrid solutions are discussed. Section 3 describes the proposed algorithm and the environment and parameters of the simulation. In Section 4, we present the obtained results to evaluate the performance of the OSNW protocol in comparison to other existing DTN protocols. Lastly, Section 5 concludes the paper

2. Delay Tolerant Networks

During the same era as the Internet of Things (IoT), another category of networks, known as Delay/Disruption Tolerant Networks (DTN) or Opportunistic Networks (ON), was developed to address routing challenges in networks where a stable end-to-end path is often unavailable [4]. Such networks, termed "challenged networks," are characterized by their lack of a stable and direct path from source to destination, primarily because they lack a traditional infrastructure [3, 4, 5]. These networks experience frequent disruptions and have limited resources, while their nodes exhibit high mobility and dynamic behavior. DTN leverages the inherent mobility of these nodes to opportunistically establish paths and transmit messages from one node to another. Mobile nodes move within different clusters, carrying and forwarding messages across the network to their intended destinations.

Initially, DTNs found applications in scenarios like wildlife tracking in challenging terrains using sensor networks, military operations, underwater exploration, Satellite networks, and more. DTN's success in these applications is attributed to its ability to overcome the challenge of establishing continuous network connectivity, even in remote or dynamic environments where a complete and stable path from source to destination cannot be guaranteed. In such demanding conditions, traditional infrastructure-based routing protocols are naturally unsuitable due to the inherent nature of their design.

2.1 DTN and IoT Interdependency

A literature analysis reveals several striking similarities in the design concerns, node/traffic behavior, resource constraints, and performance metrics between Delay-Tolerant Networking (DTN) and the Internet of Things (IoT). As a result, a multitude of solutions has been devised, employing hybrid mechanisms. These DTN-enabled IoT network solutions empower smart objects to communicate more efficiently, even in the face of frequent disruptions, effectively addressing the overarching concern of constrained device lifetimes. Recent research studies underscore that the integration of DTN within the IoT framework yields the most suitable and satisfactory results. This interdependence between DTN and IoT is visually depicted in Figure 1.

2.2 DTN Routing and protocols

DTN can offer deterministic solutions as compared to a fully Ad-Hoc environment. Applications with large area coverage and heterogeneity are not very effectively handled using the existing TCP/IP model. A few of the primary reasons for the lack of suitability of only the TCP/IP protocol stack architecture are as follows:

1. Centralised nature
2. Maintenance of very large routing tables.
3. Connection orientation

Maintaining the above features would incur heavy expense, in the case of a partitioned and multi-hop environment. Therefore, DTN schemes in the IoTb environment will be very suitable and have much better handling potential for lightweight applications. These solutions can be implemented separately very much like WSN and MANETs, or they can be implemented within the existing infrastructure.

DTN is designed as network architecture with adaptation for variation and long latency. The basic principle of DTN is to use this very flaw and incorporate it into the system by having a store-carry-forward mechanism.

All DTN routing solutions use this approach, it allows for some latency by keeping the data units to be stored in the transmitting nodes instead of directly forwarding. This also does not require maintaining large network forwarding tables like infrastructure networks [1,10,13,18]. The three primary classes of DTN solutions are:

1. Bundle Based

2. Routing Based

3. Others referred to as X-DTN

Bundle Based. The Bundle Protocol (BP) is designed to transport packets in the form of messages or bundles, rather than as individual packets. Bundling facilitates the transmission of multiple packages in a message-oriented manner over a disrupted network. It essentially serves as an overlay atop the existing network infrastructure. This concept draws inspiration from solutions initially developed for Wireless Sensor Networks (WSN), which are characterized by their disruptive mobility, where data can be locally stored at each node until the next hop becomes available.

The fundamental change introduced is the incorporation of a convergence layer above any transport layer protocol. This is a significant development as it ensures uninterrupted interoperability without necessitating modifications to the existing Physical and MAC (Media Access Control) layers. Additionally, it offers a practical approach to addressing security concerns within the network architecture.

Routing-based. This category of protocols addresses three primary criteria essential for devising effective solutions: route selection, the degree of replication, and the selection of optimal next-hop or relay nodes to minimize the forwarding requirements for routing. An equally vital aspect to consider is efficient buffer management, with the aim of reducing both packet loss rates and delivery delays. In this paper, we propose an alternative mechanism designed to enhance the performance of the Spray and Wait routing protocol, comparing it with several existing protocols. This specific protocol has been chosen for its attributes, such as bandwidth efficiency, scalability, and suitability for devices with energy constraints. Therefore, it stands out as a promising solution for enhancing the efficiency of existing IoT networks.

2.3 Literature Survey of DTN Routing protocols

In the context of routing protocols, a division into two main components becomes evident: the Forwarding part and the Replication part. The evolution of these protocols aims to mitigate the drawbacks of flooding mechanisms, which tend to be inefficient and undesirable. Flooding often leads to redundant and duplicate copies of the same message, resulting in network congestion and wastage of valuable resources. Furthermore, nodes must employ buffers to store messages, but these buffers have finite capacity. Consequently, a high number of dropped or timed-out packets can occur, leading to bandwidth wastage and reduced overall efficiency.

Hence, the primary criteria for evaluating these routing protocols revolve around achieving efficient delivery to the destination while minimizing the number of replicas and lost messages and reducing latency. Most protocol designs concentrate on two key aspects: the number of copies (single or multiple) and the quantity and suitability of forwarding nodes [14,15].

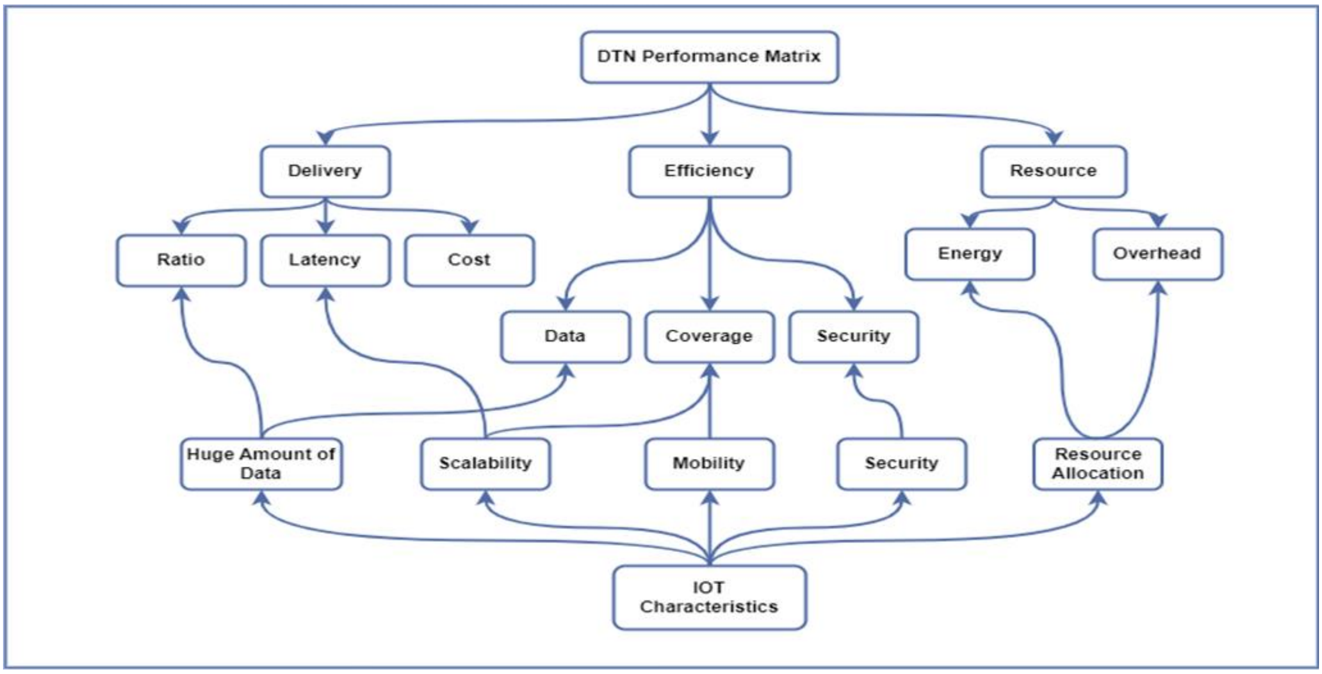

Fig. 1. Interdependency of DTN and IoT

Since the objective is not merely assured delivery but also cost-efficient routing in terms of hops and replicas, routing protocols, often referred to as replication-based algorithms, are broadly categorized into two classes. These classes are determined by the extent of replication: Limited or Unlimited. Unlimited replication-based algorithms [14] involve replicating bundles and flooding them to all reachable neighbours. While this approach offers a high delivery probability, it significantly increases overhead and resource consumption, which is a concern in resource-constrained Delay-Tolerant Networks (DTNs). As a result, there is a clear need to strike a balance between these two requirements [9,10,11].

Recent developments have seen the emergence of DTN routing protocols tailored to the context of the Internet of Things (IoT) [6]. These advancements include considerations of heterogeneity, such as smart grids and drones (Unmanned Aerial Vehicles or UAVs), each utilizing different DTN routing protocols.

The Table 1 shows the evolution of DTN routing protocols and adaptation for IoT:

3. Proposed approach

The proposed approach OSnW modifies the buffer capacity usage. The resource efficiency introduced would make this suitably useful for the IoT environment, especially low-power/memory sensor-based scenarios. Two new variables represented by 'Eligibility' of transfer & 'Priority' in the buffer queue are introduced. The queue is being managed as per 'Priority'. Therefore, the proposed approach would be referred onwards as"Optimized Spray And Wait" or abbreviated to" OSnW".

Reference	DTN routing protocol	Replication Strategy	Routing Strategy	Year	Adapted for IoT
[6]	Epidemic	Unlimited	Flooding	2000	-
[8]	Prophet	Controlled	Forwarding	2003	-
[8]	Spray and Wait	Controlled	Flooding	2005	-
[9]	Maxprop	Controlled	Forwarding	2006	-
[10]	Spray and focus	Controlled	Flooding	2007	
[1]	RAPID	Controlled	Flooding	2010	-
[1]	Prophetv2	Controlled	Forwarding	2011	-
[15]	IoB-DTN	Unlimited	Flooding	2018	Yes
[16]	Hybrid type dtn routing protocol considering storage capacity	Hybrid	Hybrid	2019	Yes
[17]	Scheduling-PROPHET	Controlled	Forwarding	2019	Yes
[18]	Multi-objective based deployment of throwboxes in delay tolerant networks for the Internet of Things environment	Hybrid	Hybrid	2020	Yes
[19]	Energy efficient emergency rescue scheme in wireless sensor networks	Controlled	Forwarding	2021	Yes
[20]	A novel communication framework between MANET and WSN in IoT based smart environment.	Controlled	Forwarding	2021	Yes
[21]	IoT enabled smart dustbin with messaging alert system.	Hybrid	Hybrid	2022	Yes
[22]	Agent driven resource scheduling in wireless sensor networks: fuzzy approach	Hybrid	Hybrid	2022	Yes

[23]	A novel scheduling algorithm development and analysis for heterogeneous IoT protocol control system to achieve SCADA optimization	Hybrid	Hybrid	2023	Yes

TABLE 1:The evolution of DTN routing protocols and adaptation for IoT

The OSNW routing protocol has a sequence of the following two phases:

1. Spray

2. Wait.

In the first phase, the message is 'Sprayed' thereby being replicated into a limited number of copies (as S&W is a limited-replications method) and then forwarded to several neighbour nodes. These nodes then in turn also engage in further spraying of the message, in a tree-like fashion.

Different variations use different types of spraying and

replication mechanisms.

After spraying the Wait phase begins. In this phase, the nodes wait till the message is delivered to its destination. If it fails to be delivered to the destination, the protocols switch into a direct delivery routing approach and the message is delivered directly. So, this protocol combines the features of having higher speed and simplicity as it combines epidemic routing and the direct delivery routing protocol.

The performance assessment and scope of improvement/modification of any routing protocol are dependent on the delay or latency, that it takes to deliver packets correctly and the number of copies required. As per this the work can be divided into two parts that can be modified separately or together:

1. Scheduling part: The strategy or way of sending messages to the next node(s)
2. Buffer Queue Management part: The strategy or way of deciding which message to delete from the messages in the buffer queue.

Both of these strategies can impact the performance of a routing protocol in significant ways. A variety of

scheduling methods are used, ProPHET uses the history of encounters [5] with other nodes, a statistical property of two parameters delivery predictability and transitivity. And the standard buffer management method is First-In-First-Out.

In this paper, the proposed algorithm suggests a modification to both of these two strategies to implement a buffer-adapted variation. The proposed modifications are as follows:

Scheduling Strategy: The proposed algorithm tries to reduce the flooding in the network by putting some conditions based on a new parameter. If the receiving node satisfies those conditions, then the sender will forward the message further, otherwise, it will not forward it to that node. The first condition is that if the receiving node is not the destination node then it should have at least two connections to forward the message further. The second condition is that it should be at a minimum distance from the sender node or has a minimum buffer load. This ensures less replication and a local minimum is achieved. As it is known that the shorter the distance, the higher is the delivery probability. Likewise, the lower the buffer load higher the chances that the message will not get dropped.

$$\mathrm{ED_{best}} \propto \frac{1}{\mathrm{distance}} \quad (1)$$

$$\mathrm{ED_{best}} \propto \frac{1}{\mathrm{buffer\ load}} \quad (2)$$

$$\mathrm{ED_{best}} \propto \frac{1}{\mathrm{distance}} * \frac{1}{\mathrm{buffer\ load}+1} \quad (3)$$

Effectively the sender will compute the ‘ED_best or Best Delivery Eligibility’ of each node in the communication range and will forward the message to only the best two routers. And these the receiving node would have at least 2 connections and would have maximum eligibility value.

Algorithm 1 The Scheduling Process for calculation of *ED_{best}*

Input: $ED_{initial}$, initialisation of Eligibility for a node in the Neighbour circle

$S = \{s_i \mid 1<i< n\}$, set of all nodes in the network

$E_i = \{s_k \mid n_{ik} \neq 0, 1\leq k\leq n\}$, set of nodes encountered by node s_i,

Initialize $ED_{initial} = Null$, for node S_i;

1: **if** s_i, Encountered s_j, and $s_j \notin E_i$, **then**

2: $E_i = E_i \cup \{s_j\}$

3 **if** $s_j \notin ED_{best}$ **then**

4: $D_{(i,j)} = | E_i \cap E_j |$

if $D_{(i,j)} > ED_{threshold}$ **then**

$ED_{best} = ED_{initial} \cup \{s_j\}$

End if

End if

End if

Queue Management Strategy:

The Epidemic and many other routing protocols in DTN follow the First-In First-Out mechanism. This is to say that any message in the buffer queue would be processed in the FIFO order for scheduling to the next eligible node. Once the buffer is full any newly arriving messages will be stored and the oldest message in the buffer queue would be deleted and discarded regardless.

The proposed work applies three new strategies to utilise the space in the buffer queue adaptively based on a new variable '$P_{Transfer}$ or Transfer Priority' message and compares them with 3 of the most applied protocols.

$$P_{transfer}(x,y) = P_{transfer}(x,y)_{old} + (1 - P_{transfer}(x,y)_{old}) \times P_{transfer_{init}} \quad (4)$$

$$P_{transfer}(x,y) = P_{transfer}(x,y)_{old} \times \gamma^{k} \quad (5)$$

Where γ is an ageing constant [2, 3] and $\gamma \in [0,1]$ and k is the ageing factor that depicts the time that has elapsed since the last delivery to that destination.

The rationale behind the proposed strategy is to identify the optimal path among the various possible paths. This traversal problem can be modelled as a resource, in this case, buffer, allocation model in which an incoming or existing packet will be discarded or assigned buffer space, to maximize the probability of the packet reaching the destination node. This is a combinatorial optimization, similar to a knapsack problem with a single limitation, which is an NP-hard problem. And hence an optimal solution can be obtained from a large set of possible solutions.

Due to the mobility, low energy and space requirement of sensors and devices in IoT, network routes are unpredictable and unstable and therefore delay tolerance is required. Therefore, instead of solving the end-to-end problem, the routing is converted into a set of simpler sub-problems. The optimal substructure ensures an overall optimal solution. The pseudo-code for the proposed strategy is given below followed by a detailed explanation of the same:

Algorithm 2 The Queue Management Strategy for calculation of $P_{transfer}$

Input: $S = \{s_i \mid 1<i<n\}$, set of all nodes in the network

$R_i(m_k)$, the replicas of message m_k carried by node s_i,

NC_d, the Neighbour circle of the destination

nNodes, the number of neighbour nodes in S_i's transmission range

SM_i, set of messages in queue carried by s_i,

SM_j, set of messages in queue carried by s_j,

Initialize $P_{transfer}$ = *Null*

if s_i encounters s_j and $R_i(m_k)) > 1$ and s_j NC_d **then**

update $P_{transfer(i,j)}$ and NC_i

$SM = SM_i \cap SM_j$,

for each message m_k in SM **do**

$s_d = m_k$'s destination

if $s_d == s_j$ **then**

s_i directly forwards m_k to s_j

else if $P_{transfer(i,d)} < P_{transfer(j,d)}$ or nodes < 2 **then**

$R_j(m_k) = \lfloor R_i(m_k)/2 \rfloor$

add $L_j(m_k)$ copies of m_k to $P_{transfer}$

end if

end for

if $P_{transfer}$!= *Null* **then**

sort $P_{transfer}$ in ascending order of TTL

s_i forward $P_{transfer}$ to s_j

end if

end if

The first strategy is to delete the message whose destination has been encountered by the node most recently. Because the nodes keep flooding the same messages until they are in their buffer. It means a node is receiving the same messages many times it may have forwarded the same message to other nodes many times. So, keeping this thing in mind, the proposed algorithm is deleting the message whose destination has been encountered by the node most recently.

In our second queue management strategy, the nodes will delete the message whose destination has been encountered least recently. In this way, the proposed algorithm is applying the idea that the node will not receive the message with the destination address which the node has encountered least recently anytime soon. So, the node will delete that message. If there is a situation in which two or more message destinations have the same encountered age then in that case proposed protocol is applying the First In First Out strategy in which the node deletes the oldest message in the buffer. So if two message destinations have the same encountered age then the protocol will delete the older message.

The third strategy is to delete the message whose destination address is farthest from the node. As earlier stated, the delivery probability is inversely proportional to the destination distance. So, the proposed algorithm has used the same idea here. If the destination node is very far away from the current node then delivery probability gets reduced and as DTN nodes have limited resources, the protocol will use those resources on those messages whose probability to get successfully delivered is higher. In this way, it will reduce the overhead and simultaneously increases the delivery probability.

Each node maintains a delivery probability table that shows the probability of a message getting delivered to the destination from the last wait cycle. Whenever nodes meet, they exchange their delivery predictability table and update their delivery probability table. Transitivity is if node X frequently encounters node Y and node Y frequently encounters node Z then node Z is a good relay to deliver the message to node X. As each node calculates the delivery predictability for all known destination nodes where $P(x, y) \in [0, 1]$. To calculate delivery predictability where a node encounters another node:

This protocol assumes that the bandwidth is unlimited so the time taken to deliver messages is ignored. The transitivity property decreases the message dropping rate and it also helps in decreasing the time a message wastes in the queue of a node. It lowers the load and the pressure of a node.

3.1 Simulation Environment

This Simulation of DTN routing protocol cannot be efficiently performed by tools used for traditional networks. The DTN routing protocol requires node and route characteristics that deal with mobility, intermittent connectivity and resource constraints.

One of the most prevalent tools is the Opportunistic Network Environment (ONE) simulator. This software facilitates the modelling of different scenarios for existing and new DTN routing protocols. It is a powerful tool that allows recreating and testing of Epidemic, Spray and Wait, MaxProp, Rapid and ProPHET very easily. The ONE simulator is specifically designed for the investigation, comparison and evaluation of various DTN routing protocols.

3.1.1. Advantages and evaluation parameters of ONE Simulator

Among these software tools suggested above, the ONE simulator is most suitable as it has network scenarios that are designed specifically for evaluating the DTN routing protocols. Therefore, this paper uses the ONE simulator for implement and comparison of the new and existing DTN routing protocols.

The ONE simulator depends on mobile node movement, the density of the nodes, and the distance between the sender and receiver. These factors significantly affect the performance of the DTN routing protocols in terms of relying on latency, the delivering probability, and the overhead ratio, among other factors. The main criteria are to identify a suitable routing and forwarding approach and match these techniques with real-time mobility.

The ONE simulator is open-source software that allows front-end editing and execution of programs for development and result visualisation. However, the software requires Eclipse IDE for Java Developer v.2020-06. The ONE simulator software can be compiled in both ways, through Windows or using Eclipse IDE. Another feature of ONE simulator is the generation of mobility traces, running the DTN message, visualization of the simulation and presentation of a log of the results of execution.

3.1.2 Metrics of Performance & Simulation parameters

Several factors are commonly utilized for the assessment of the performance of DTN routing protocols: overhead ratio, packet delivery ratio, average latency, and average hop count [15], [16]. These metrics are described as follows:

a) Overhead Ratio: One of the most important metrics used to assess the performance of DTN routing protocol Overhead Ratio. It can be defined as the number of duplicate packets that are required to be transmitted to ensure successful delivery. The overhead ratio provides a measure of the network congestion status, which is used to determine the bandwidth required and the number of successful replications required for the packet delivery [5], [21]. It is given by Eq. (7):

$$OR = (R - D)/D \quad (7)$$

Where R is the number of successful transmissions and D refers to the number of messages delivered to the destination [15], [16].

b) Delivery Probability: The delivery probability is yet another important metric to assess the performance of any DTN routing protocol. It is a measure of the ratio of the actual number of packets delivered to the destination and the actual number of packets sent from the source node. A high packet delivery ratio signifies less loss and thus better performance of the network It is calculated as presented by the authors in [15] and [16], and is given by Eq. (8):

$$PDR = DM/CM \quad (8)$$

Where DM is the number of successfully delivered messages, while CM is the number of created messages.

c) Average Latency: Average latency is defined as the time elapsed from the time the message is sent from the source node to the time it is delivered at the destination node. That is to say, it is the average time taken by the message to be created by the source node till the time it is received by the destination node [21].

d) Number of Hops: According to Baek et al. [5], the hop account is defined as the number of nodes that a message has been sent to thus far. If the message is created at a node, the hop count is calculated as zero. That is to say, the hop account indicates the number of hops that the message makes between the source node and the destination node [21].

The simulation parameters considered for analysis in the DTN routing protocols are summarized in Table 2

TABLE 2 .List of simulation parameters

Parameters	**Values**
Simulation Area	4500*3400
Simulation Time	43200
Mobility Model	Shortest Path Map-Based Movement
TTL	300
Buffer Size	5MB
Transmission Range	10
No. of Nodes	126
Bundle creation rate	25 to 35 seconds
Bundle size	500kB - 1MB

4. Results and Discussion

The results of the ONE simulation have been generated through reports that are created by report modules during the run time of the simulation. The Simulation engine provides the data to the report modules for the run-time events, reports are then created based on these received results.

As suggested above, the routing protocols reports contain measures and values for different factors such as lateness, packet delivery ratio and bandwidth consumption.

4.1 Reporting and Visualization

There are two ways to visualize the simulation results in the ONE simulator:

(i) generating images from the information gathered during the simulation, and

(ii) via an interactive GUI. The simulator has a graphical user interface (GUI) that is launched with Java. It is possible to zoom in and out and to change the speed by using the GUI update icon in this playfield graphics in the ONE simulator. The playfield graphics has various buttons and icons to play the simulation step forward internally, enable and disable fast forward, and play the simulation for a specific time.

Consequently, this paper has conducted a comparative analysis by pitting our implemented routing protocols against Epidemic and ProPHET. The results demonstrate that the proposed protocol surpasses Epidemic, ProPHET, and Stop-and-Wait routing protocols in several key performance metrics. The assessment was based on parameters such as delivery probability, overhead, the number of hops, and latency.

The simulation results and subsequent discussion present a set of comparative graphs showcasing the performance of the three existing protocols in comparison to the proposed 'OSnW' approach.

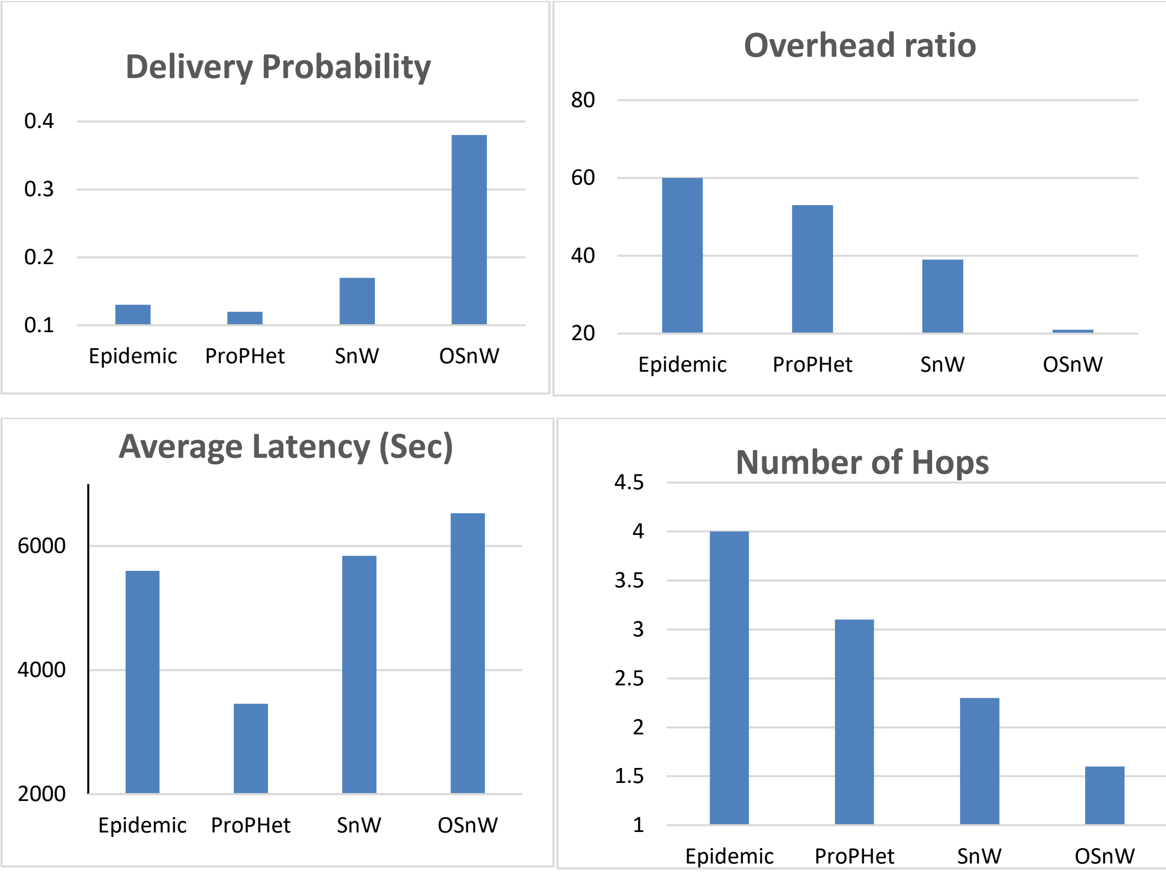

Fig.2. Comparative graphs for Epidemic, ProPHet and SnW protocols with the proposed approach 'OSnW'

As evident from the graphs for all 4-performance metrics, the proposed approach outperforms the existing protocols. It can be noted that for most parameters Epidemic and Spray and Wait protocols offer quite similar results, which are considered the optimum compared with the other protocols. In contrast, the PRoPHET behaves differently and represents the latency due to its history requirement. The number of hops, also consistently improves among the four routing protocols for the same set of simulation parameters. Thereby reflecting the overall superiority of the proposed approach.

5. Conclusion

Numerous recent surveys and research endeavors have delved into the application of Delay-Tolerant Network (DTN) routing protocols in traditional networks. However, only a limited number of these efforts have specifically tackled the challenge of enabling delay-tolerant Internet of Things (IoT). The proposition of protocols and solutions dedicated to DTN within the realm of IoT is a relatively recent development, offering substantial scope for further exploration and practical applications.

This paper aims to bridge this existing gap by presenting the design of an adaptive buffer DTN-based routing protocol, tailored to effectively facilitate a delay-tolerant IoT architecture and related applications. The paper systematically elucidates the points of convergence and intersection between infrastructure-based IoT and the seemingly infrastructure-less DTN. Both areas are comprehensively examined, taking into account their advantages and limitations.

The paper further investigates and affirms the feasibility of adapting existing DTN architectures to suit IoT applications, while considering resource constraints and other related limitations. This adaptability is underscored by the superior performance of the proposed routing scheme. In conclusion, it can be confidently asserted that this represents a promising and intriguing area of exploration for research communities. The convergence of DTN and IoT solutions holds the potential to usher in the development of new and enhanced solutions catering to a wide range of existing and emerging IoT applications.

6. Data Availability Statement

The Data used in the research was generated by the ONE simulator and shall be made available as required.

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