# Forwarding Strategies in NDN-Based Wireless Networks: A Survey

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***Abstract*—Named Data Networking (NDN) is a promising Internet architecture paradigm of the future that adopts the Content Centric Networking (CCN) approach. Applications and users only care about the contents, while the Internet protocol (i.e., TCP/IP) focuses on communication by specifying and discovering the device location, which makes it more difficult and limiting. NDN supports the efficient distribution of the content, and secures the content rather than securing data channels. The forwarding mechanism in NDN-based wireless networks including MANET, WSN, VANET, and WMN are very important for efficient communication. NDN provides us a robust and simple communication mechanism. Two types of packets are exchanged over the networks in NDN forwarding: INTEREST and DATA. In this paper, a detailed survey is provided regarding forwarding strategies and forwarding issues in NDN/CCN based MANETs, VANETs, WSNs, and WMNs. Future challenges regarding forwarding in wireless environment are also highlighted.**

***Index Terms*—Named data networking, CCN, forwarding, MANET, VANET, WSN, WMN.**

## I. Introduction

NAMED Data Networking (NDN) is a newly proposed paradigm and a candidate for future Internet architecture. It provides advantageous assurances and promises in distributed wireless systems. Exceeded applications and Internet usage challenges the abilities and capabilities of today's TCP/IP based Internet architecture to support and secure end-to-end communications because of the lack of centralized communication control, intermittent connectivity, dynamic topologies, node mobility, and signal propagation. NDN offers new and smart ways of thinking about network architecture of the future. NDN is the understanding of networks not by considering the IP but the environment of networks. The architecture mismatch and usage of today's Internet are the motivations behind the NDN. NDN is an extremely capable architecture that supports Internet applications and services. A research activity on NDN under the future Internet program is funded by the U.S. National Science Foundation [1].

The main motivation of NDN is to generalize the network layer to names of content (information) to the end point like today's IP architecture. NDN is a clean slate, new architecture design independent of IP [2], and is based on receiver-driven communications. Two types of packets are exchanged over the networks: INTEREST and DATA packets. The Consumer sends the INTEREST packet, while the Provider receives the INTEREST packet and sends the DATA packet back to the Consumer. The INTEREST packet contains the name of the desired data piece, which might be a part of the requested contents that the Consumer sends to the networks. Routers forward the received INTEREST packets to the Provider, which holds the requested content or data. Once the INTEREST packet arrives at the destination, a DATA packet containing the requested content name and content itself along with the producer's signature stamp will be returned by the Provider. This DATA packet follows the same path as the INTEREST packet travelled. Remarkable NDN features such as network caching, location independent named data, and lightweight forwarding makes it an extremely stunning and attractive solution for mobile ad hoc networks. Data immutability, hierarchical naming, universality, in-network discovery of names, securing data in direct ways and hop-by-hop flow balance are NDN's protocol designs [2]. Both NDN and IP share the same hour glass, send datagram, end-to-end principle, and usage of own-name space for data delivery. NDN maintains the same hourglass-shaped architecture as the original Internet [4], as shown in Fig. 1. INTEREST message flooding is a hot research issue in MANETs because participant nodes with limited resources frequently participate in the forwarding process and die earlier due to insufficient residual energy.

There are issues of content delivery and packet forwarding in mesh networks due to unstable and narrow wireless links. End-to-End principle, plane separation of routing and forwarding, state full forwarding, built-in security, and user choice enabler are the key NDN architecture features. Establishment of trust anchor and effective solution for trust management in NDN makes the NDN secure for communication. The built-in feature of producer signature in data packet ensure the privacy and the safety of the massages. If in-order INTEREST delivery is an application's requirement, then we need to find a forwarding mechanism and effectively prevent it from packet congestion and packet loss. NDN's paradigm leads to a new network forwarding plane that can circumvent prefix hijackers, use multipath to control congestion, and successfully avoid

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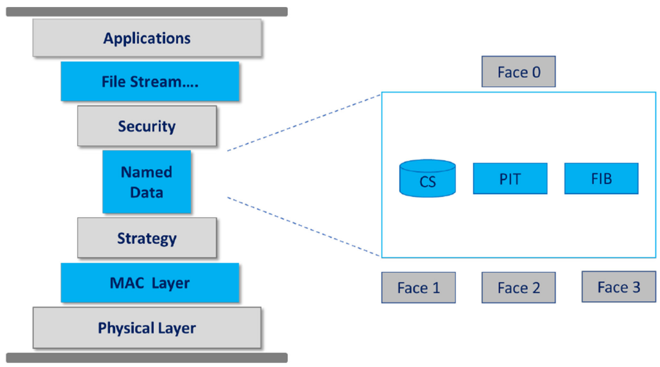


Fig. 1. NDN hourglass architecture.

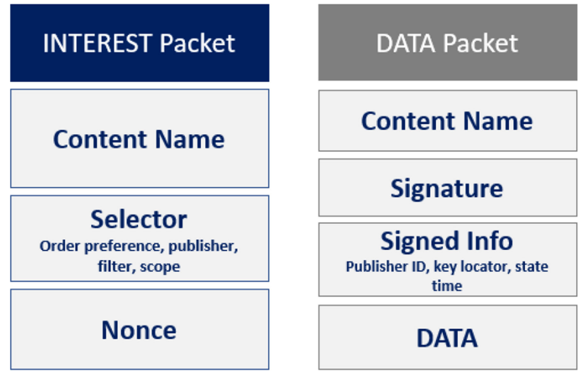


Fig. 2. NDN INTEREST and DATA packets formats.

failure links. NDN requires fast, variable-length, hierarchical name-based lookups, large scale forwarding tables, and per packet DATA state update. The scalable packet forwarding is still a challenging area. Fast name look up, intelligent forwarding strategies (preferred route), and caching policies are the key functions of NDN forwarding [9]. The major issues related to the NDN forwarding are: exact string matching (insert, delete, and update operations) with fast updates, flow maintenance at large scale, and longest prefix matching for variable length and unbounded names. These problems require constant time operations, optimization needs URL format, fast update requires simple DATA structure; efficient packet encoding and decoding along with content store policies are also efficient solutions [9]. In this paper, we will discuss the architecture of newly proposed futuristic Internet paradigm NDN and CCN.

The focus in this paper is on forwarding strategies and forwarding issues in NDN/CCN-based wireless networks such as mobile ad hoc networks (MANETs), vehicular ad hoc networks (VANETs), wireless sensor networks (WSNs), and wireless mesh networks (WMNs). We will present the problems and issues in contrast to forwarding plane design, applications and implemented techniques that are proposed in solution of forwarding issues. Fast name looks up along with less memory cost is the main challenge in the NDN scalable forwarding. The adaptive forwarding strategy adopts an informed decision related to control flow, multi-cast DATA delivery, updating path to support changes, and INTEREST forwarding and delivery. Outage due to congestion is a challenge that can be solved with the NDN forwarding rate limit feature. Network sniffing and Man-in-middle can be considered as issues. Many DATA structures are proposed to implement the PIT (pending Interest table), FIB (forwarding information base). In NDN architecture, the abstraction of virtual, logical and physical interfaces is a face. Every entity that wants to communicate in NDN creates a Face. The face can be logical interface, applications or physical interface. The face in NDN consist of a transport and link service mechanism. Face support different mechanism of transport depending on the hidden interface. NDN implement its overlay network using this level of abstraction on existing networking technologies [70]. Replication, delivery modes such as multi-cast, unicast and any cast, in network caching and multi-path routing make transport of DATA more complicated than that of the Internet. Data redundancy and replication issues are because of the broadcast nature of NDN.

In this survey paper, we will examine the forwarding issues in NDN-based mobile ad hoc networks MANETs, VANETs, wireless environments like wireless sensor networks, and mesh networks in detail. The paper is organized in the following manner: In Section II, we present NDN architecture, applications and system services, NDN features design principles and comparison of NDN with today's IP architecture. In Sections III–VII we will discuss wireless ad hoc networks and presented a comprehensive survey of the main ingredient of this paper that is, forwarding strategies in MANETs, VANETs, WSNs and WMNs. We Also presented a detailed comparison and performance of forwarding strategies in each of network discussed above. In Sections VIII and IX, we conclude the paper by addressing open challenges, problem issues, and future directions regarding NDN forwarding and research.

## II. NDN Architecture and Comparison With IP

NDN Architecture is a completely new paradigm architecture, but it can be grounded in current practice in terms of operations. The design of NDN architecture represents our understanding of the limitations and strengths of the currently implemented Internet architecture, that is, TCP/IP. NDN maintains the same hourglass-shaped architecture as the original Internet.

### A. NDN Packet and Router Structure

Communication in NDN is receiver driven. Two types of packets: INTEREST and DATA packets are involved in the entire communication process that contain the name of the data [8]. INTEREST and DATA packet formats are depicted in Fig. 2.

INTEREST packet: The name of the resulting data chunk is placed in the INTEREST packet from the Consumer side and is sent to the network. Network routers use specific naming information to forward the packet further in the network towards Provider. DATA packet: A DATA packet will return when the INTEREST packet arrives at the producer node that contains desired data. DATA packet contains

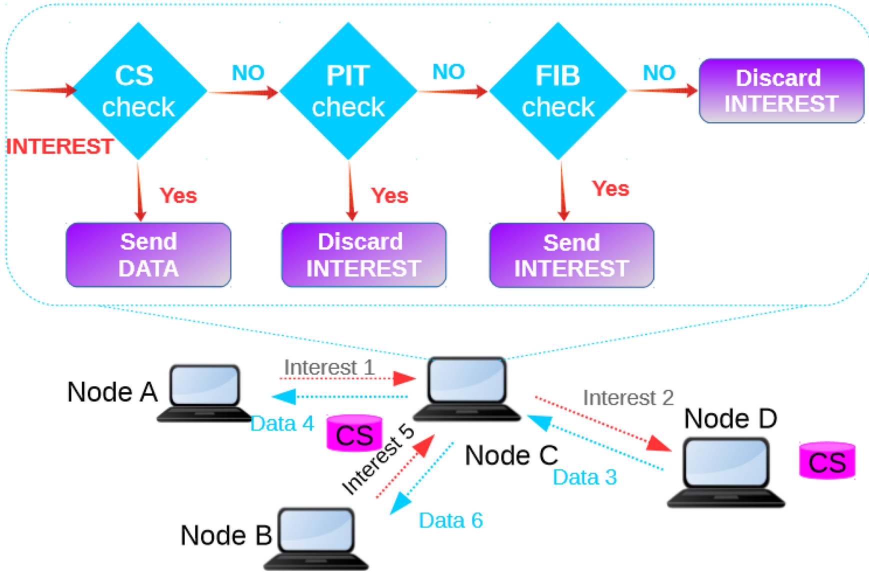


Fig. 3. Forwarding model in NDN.

the name and content, along with the producer's signature. DATA packets follow the same reverse path as INTEREST packets.

In Routers Architecture, each NDN router maintains the following three data structures.

1) Forwarding Information Base (FIB): This table is used by routers to forward INTEREST packets toward the Producer of data. Each entry of the FIB table includes a name prefix and a set of faces that show the next hop toward Producer.

2) Pending Interest Table (PIT): PIT is used to keep track of the path taken by the INTEREST packet. Each entry of the PIT table includes the name of INTEREST, set of incoming faces that shows the previous hops, and set of outgoing faces that shows the next hops taken by INTERESTs of that name. The PIT table can also be used for other purposes, such as aggregation of INTEREST packets and Congestion Control, etc.

3) Content Store (CS): CS is used for in-network caching of DATA Objects. CS can satisfy INTEREST packets on behalf of Producer, if they have previously cached DATA objects. In short, CS is a temporary cache of DATA objects that the router has received. Forwarding strategy module is a series of policies and rules about forwarding packets. Consumer, which is an application over a node in network, will send INTEREST for a DATA object. Then, INTEREST packet will be forwarded by routers toward the publisher of content, which is called Producer. Producer will reply to the INTEREST packet by sending the DATA object related to the requested name, and routers will forward the DATA packet toward the Consumer.

### *B. NDN Architectural and Protocol Design Principles*

NDN maintains the thin-waist hourglass [67] shaped architecture, cores on a universal IP network layer by applying the minimal necessary functionality for worldwide interconnectivity [10]. The inadequate security in current Internet architecture (IP) is being reconsidered and an increasingly hostile environment makes this worse. NDN furnishes a basic security building block by authorizing all named data, right at the thin waist. The built-in security of NDN's supports secured data transfer at the network layer by verification and signing of any named data. NDN retains the end-to-end principle and expands it because it enables improvement in strong applications and in the context of network failures. Self-regulating network traffic, stateful forwarding, and flow balanced delivery of packets and data is important for stable operations in a network. Flow balance is an important feature in NDN design. NDN routers save the state of freshly forwarded packets, and allow flow balance, loop detection, smart forwarding, and universal caching, etc. NDN sticks to the principle of routing and forwarding plane separation for best available forwarding technology in NDN deployment; research on new routing and forwarding systems is being conducted in parallel. The architecture should entertain and facilitate choice of user and competition with every best possibility. NDN makes sufficient awareness effort for the empowerment of end users and enables competition. NDN has the Internet's hourglass-shaped architecture but encourages the development of the thin waist that supports the creation of entirely general distribution networks. A comparison of NDN and IP architectures is presented in Fig. 4. The center point of this developing evolution is to mitigate the limitations that packets can only be endpoints of name communication. In the NDN packet, as far as the network is concerned, name can be an endpoint, a command to turn on some electric devices, a chunk of a book or movie etc. Through this conceptually simple change as well as control and digital problems, NDN networks can efficiently resolve communication problems. A challenge for the future of NDN research is to create an architectural framework that is very capable of resolving real world problems, particularly in poorly served application areas in which Internet addresses are used.

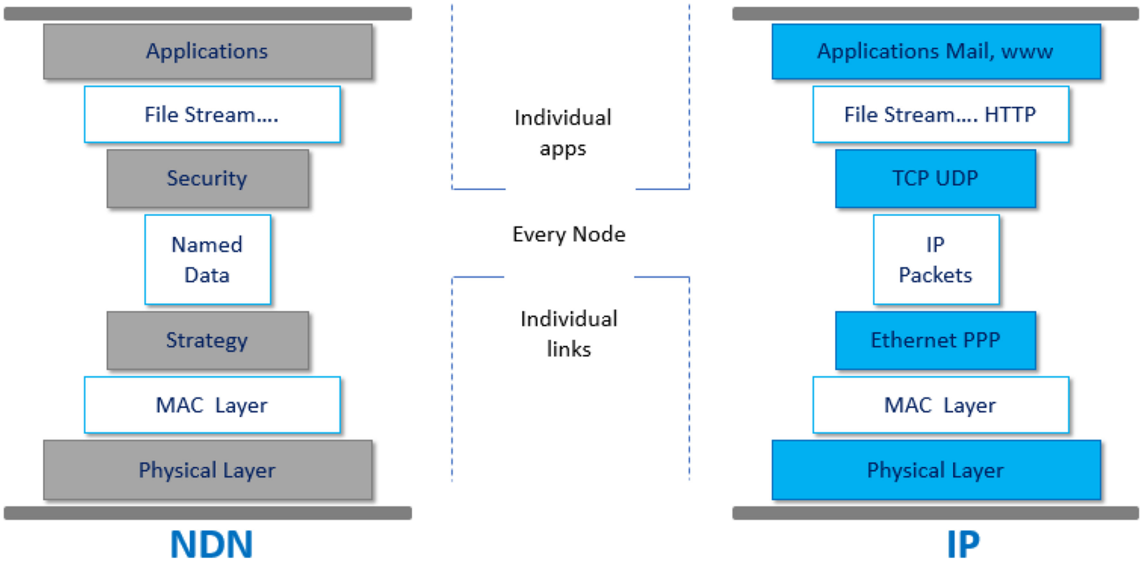


Fig. 4. Comparison of NDN and IP architecture.

NDN communication is receiver driven. A Consumer sends an INTEREST packet out to receive the DATA that carries a name to place the requisite DATA. A router keeps the interface of an incoming request in mind, searches the name in its FIB, and then forwards the DATA packet, occupied by a name-based routing protocol. A DATA packet that contains both name and content of DATA along with the Producers' key signature is sent back, when the INTEREST packet ranges around a node that has the desired/requested DATA. DATA packet travels back to the Consumer by tracing reverse path used by the INTEREST packet. Neither the DATA nor INTEREST packets contain any of the interface or host addresses as in TCP/IP. INTEREST packets based on the names, routed towards DATA Producers and DATA packets containing data and name returned, are set up by INTEREST at each of the router hops. NDN routers keep both INTEREST and DATA for some period. In case of multiple INTERESTs for the same data, only the First received INTEREST is sent towards the source of DATA. Thereafter, the information about the INTEREST packet is stored in PIT by the router. Each entry in the PIT table comprises of INTEREST name and a set of matching INTEREST interfaces. The router finds the matching PIT entry, when the DATA packet arrives and forwards the DATA to interfaces that are listed in the PIT entry [4]. The router then relocates the related PIT entry and caches the data in CS. Across each hop, one DATA packet satisfies only one INTEREST packet, thereby achieving hop-by-hop flow balance. DATA packets in NDN revolve around the fact of what the DATA packet contains, independent of from where it comes or where it is forwarded. Therefore, routers can cache it according to future requests. Forwarding model of NDN is shown in Fig. 3. Due to its architecture, NDN supports various functionalities like multicast, content distribution, delay-tolerant networking and mobility. It improves packet sending performance and decreases reliance on failed and corrupted data sources due to attacks [3]. NDN protocol design principles are described below [11]:

- Universality: A common network protocol for all network environments and applications should be NDN. The NDN packet format should be extensible and flexible.
- Data-Centricity and Data Immtability: Immutable desired DATA packets should be fetched unambiguously and be uniquely named by NDN that are requested using INTEREST packets.
- Securing Data Directly: An important consideration is that DATA packets should be secure and are not affected by mobility.
- Hierarchical Naming: Packets should carry hierarchical names to embellish structured context and enable demultiplexing.
- In-Network Name Discovery: Ability of INTERESTs to identify incomplete names to retrieve and fetch DATA packets.
- Hop-by-Hop Flow Balance: For hop-by-hop flow balance, one DATA packet as a result of one INTEREST packet policy is important. In this manner, each node can have control load on its link. Guessing and controlling could be made better by limiting the INTERESTs.

### C. Limitations of IP vs NDN

In this section, restriction of the current IP Internet architecture in structural, performance, and functional properties are analyzed. Limitations inherent in the IP Internet are in context of support for curse mobility, routing and forwarding, content distribution, network security, capability of content caching, and application deployment. In an ad hoc manner, all discussed problems cannot be completely fixed. There is a desperate need for a new Internet paradigm that is capable of coping with the disadvantages of the current IP Internet, and solves the challenges with modest, effective, and efficient

TABLE I
COMPARISON OF NDN AND IP

| NDN | IP |
|---|---|
| Future Internet Architecture | Current Internet Architecture |
| Content centric | Address Centric |
| Storage is In Network | No In-Network Storage |
| Bandwidth optimization | Bandwidth is not optimized |
| Reduction in Congestion and Improved throughput | Congestion occurs |
| Stateful data Plane | Stateless data plane |
| Adaptive forwarding | Non Adaptive forwarding |
| FIB, PIT, CS | FIB |
| Content Distribution Handled efficiently | Inefficient content Distribution |
| Not Host Centric | Host Centric |
| Multipoint to Multipoint | Point to Point |
| Existing Routing Protocols Broadcast based On Name Prefix | Existing Routing Protocols Based on Address Prefix |

results. Packets using the destination IP address identify the end host in IP, while on the other hand, NDN packets use CN (content name). Forwarding of IP packet needs IP prefixes but name prefixes are used in NDN, for forwarding the INTEREST packet. Providing loop-free IP paths depends on routing protocol, while in NDN, the CN and Nonce fields are sufficient to get rid of looping.

IP forwarding is stateless and NDN forwarding is stateful because packets are not documented in the IP routing table; however, the NDN router keeps a record of every passing INTEREST packet for its entire lifetime. Data plane performance is observed continuously in NDN through INTEREST NACK, PIT states, and RTT calculation; on the other hand, IP cannot observe this because of stateless forwarding and one-way traffic. Failures in packet forwarding are handled by Internet routing protocols, which require consistent routing tables and hence results in a high overhead in a large-scale network. In NDN, failures are handled locally by forwarding strategies through periodic packet probing from outgoing router interfaces. In Internet, IP packets follow random paths to reach the destination, thereby causing congestion. Explicit congestion control strategies are presented in IP, while in NDN, the congestion is controlled by the routers. In [66] a comprehensive comparison of NDN and IP based network on Palapa Ring network is discussed with three metrics: delay, throughput, and packet drop; where IP implements all functionality for global interconnectivity and NDN is an entirely new architecture that focuses on its contents instead of the address to get that contents. This comparison provides a comprehensive study on the difference in architecture, functionalities, and forwarding strategies between current Internet architecture and future NDN Internet architecture. The limitation and the differences between the Internet IP and NDN have been summarized in Table I.

## III. FORWARDING IN WIRELESS AD HOC NETWORKS

Wireless ad hoc network is a kind of decentralized wireless network. Since it does not depend on pre-existing infrastructure, such as access points in infrastructure wireless networks and routers in wired networks, we call this network an ‘ad hoc network’. Each node participates in the forwarding and routing process, so the decision of the forwarder node is made dynamically based on the routing algorithm and network connectivity [12]. Ad hoc networks can face technical challenges in different scenarios that can affect deployment and efficiency. Signal propagation may be adversely affected by damage such as path loss, interference multipath shadowing, and fading effects. These damages can result in packet error and packet loss, as well as have an effect on distribution control of messages. The broadcast wireless channel can experience packet redundancy and collision problems. The distributed channel access is based on carrier sensing in wireless networks, and there may be trouble in exposed and hidden terminals with throughput change. Multi-hop dynamic scenarios can also experience this. Topology alteration may lead to origination network segmentation and effect routing performance, as well as result in poor, periodic, and temporary connectivity with the negative effects of constrained resources. Four types of wireless networks are discussed in this paper.

1. Mobile ad hoc networks (MANETs)
2. Wireless sensor networks (WSNs)
3. Vehicular ad hoc networks (VANETs)
4. Wireless mesh networks (WMNs)

Wireless mobile ad hoc networks are dynamic and self-configuring networks with freely moving nodes. In VANETs, there is communication between vehicles and roadside equipments. Each node is fully connected to every other node, forming a “mesh”. Google Home, Google On Hub and Google wi-fi support Wi-Fi mesh networking. Information linked to an explicit parameter, such as temperature, noise, pressure, and humidity etc., are collected through sensor devices.

In our survey paper, we presented a comprehensive research work on the forwarding in different wireless networks. We discussed Flooding based forwarding strategies, aware forwarding strategies, energy efficient forwarding strategies and congestion control forwarding strategies in detail in our document. First, we will take a comprehensive look on the forwarding strategies and their comparative analysis in NDN based MANET. Then we discussed the forwarding in NDN based VANET, WSN and Wireless Mesh Network respectively. Design of aware forwarding strategies and flooding based forwarding strategies is the need of every network. Energy efficient and congestion aware forwarding strategies can be beneficial for the MANET, WSN and Wireless Mesh network because of the dense and rush deployment of the nodes in network that are energy constrained. The detailed explanation for the designing of forwarding strategies in multiple networks is discussed in this section as well.

There should be a question that can we design any general forwarding strategy for all kinds of wireless networks? Then the answer is ‘NO’. Every Wireless and ad hoc network have its own different design principles. So, we cannot design a general forwarding mechanism for all the networks. There are some of the network that support energy efficient forwarding strategies. There are mobility issues in some of networks. The detailed discussion is as follow.

Mobility is an issue in designing the general forwarding strategy for MANET, VANET, WSN and Mesh network collectively. In MANET, nodes are infrastructure less and mobile. Mobility of nodes in MANET is variable, but most of the time there are nodes with low mobility. Different mobility patterns effect the network performance. In VANET, fast mobility scenario needs different kind of strategies as compare to MANET. Fast moving vehicles need to connect with other vehicles and the road side units for efficient data delivery. In WSN, sensor nodes are fixed as well as mobile. So, we cannot propose any strategy that support WSN with MANET and VANET. Mobility scenario in mesh network is also different.

Energy and power of mobile and sensor nodes is another issue in designing of general forwarding strategy for all kinds of wireless networks. Nodes in MANET are energy constrained but as the deployment of sensor nodes in WSN is denser that make it more energy constrained. Power consumption of the sensor nodes after such huge deployment is a serious issue. It is impossible to recharge or replace the batteries in the sensor networks. So, the design of energy and power efficient sensor nodes is crucial that will improve the overall efficiency of the network. In VANET scenario, deployment of batteries reduces the energy problem. Wireless mesh network is also energy constrained. In some cases, energy threshold limitation can handle the energy consumption while in some cases, energy harvesting techniques used for energy efficiency. So, it's quite hard to design a general forwarding technique for MANET, VANET, WSN and Mesh network collectively. Energy efficient forwarding strategies benefits MANET and WSN the most.

Adaptivity and connectivity is another issue regarding designing of general forwarding strategy. There must be support for sensor node's adaptivity in topology and density change after the node's failure, move, join or termination. The mobile nodes in MANET and VANET connect and remove their connection with the topology rapidly. Rapid change in VANET topology makes it even harder to manage compared to MANET, WSN and Mesh networks.

Congestion control strategies can be designed for MANET, WSN and mesh networks but in VANET scenario there is no need for forwarding strategies that control the congestion. Vehicles connect with the network for a limited time then move away from the range of network. Fast moving vehicles and rapidly changing topology in VANET reduces the congestion probability.

Forwarding strategies in MANETs, VANETs, WSNs and WMNs are discussed with their comparative analysis in Sections V–VIII. We also consider all networks and all type of strategies and mark which one is suitable in which network, as well as the best performing forwarding strategies at the end of the forwarding sections. Table VI presenting the summary of suitability and best performing strategies.

## IV. Forwarding in NDN Based Mobile AD HOC Networks

Mobile ad hoc Network (MANET) is a continuously self-architectural, wirelessly connected, infrastructure-less network of mobile devices, as shown in Fig. 5. It independently moves devices in any direction and changes its links frequently to other devices, thereby resulting in extreme packet losses in a fast-changing topology. INTEREST message flooding is a

Fig. 5. Mobile ad hoc Network.

promising research issue in MANETs that can cause congestion and packet redundancy problems. Frequent participation of nodes in the forwarding process eliminates them early due to limited energy remaining. VANETs, smart phone ad hoc networks, and Internet-based MANETs are a few types of MANETs [5].

Increase in mobile devices and applications encourage the importance of MANETs. Decentralized architecture of NDN-MANETs makes the communication more robust, flexible, and efficient. Decentralized networks are typically more robust and efficient due to multi-hop fashion of relay information as compared to centralized networks. For example, if the base station stops working in cellular network setting then drop in coverage occur. In MANET, single point of failure is reduced because of the multiple path availability. MANET can be created anywhere with mobile nodes and you can easily install more nodes in it, that enhance the scalability. There is no need to build an infrastructure as well in MANET that lower administration cost. Due to the importance of content and information, the use of NDN-MANET communication is vastly regarded in the public as well as military sector. Some of the application scenarios are discussed as in [13].

Application scenarios in the military sector include creating a useful and efficient in-time communication between soldiers, headquarters and among base stations, and equipment is enabled with computing devices. In emergency scenarios, such as earthquakes, fire, flood, law enforcement, etc., timely and fast communication is needed to use energy and resources from helping agencies. Low-level application scenarios, such as home applications for communication and information-sharing, as well as crowded environments such as stadiums and taxicabs need efficient delivery of information. Data networks and application scenarios related to sensor networks are also important and need effective and good data delivery.

The forwarding strategy in NDN decides how to use multiple forwarding options efficiently and choose the best interface to forward the INTEREST packet. The design of a forwarding strategy depends on the network environment and context. This section discusses forwarding and routing strategies for NDN-based MANETs. A comprehensive presentation of the forwarding strategies in NDN-MANETs is depicted in Fig. 6.

We categorized Forwarding strategies for NDN based MANETs in five branches.

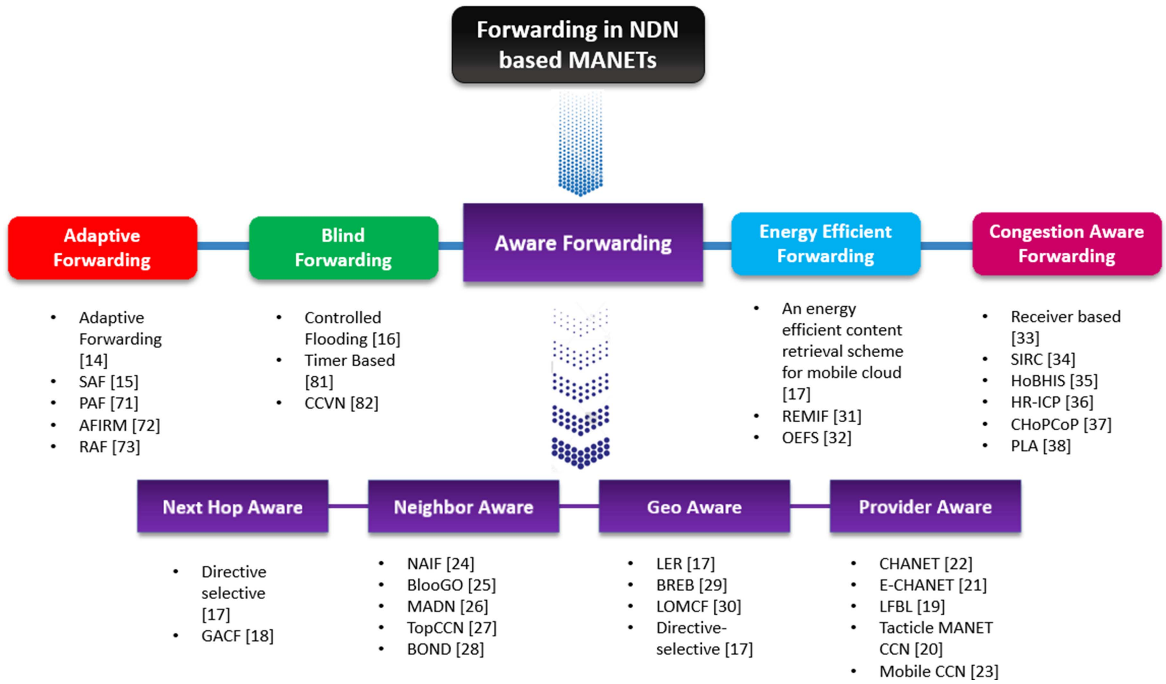


Fig. 6. Forwarding strategies in NDN based MANETs.

1. Adaptive Forwarding
2. Blind Forwarding
3. Aware Forwarding
4. Energy Efficient Forwarding
5. Congestion Control Forwarding

In adaptive forwarding, best possible path is retrieved for the DATA packet. In Blind forwarding, flooding mechanism is utilized. In which, INTEREST and DATA packets are flooded throughout the network. In Aware forwarding, as the name is represented, INTEREST and DATA packets are aware of many things such as next hop, neighbor nodes, the network, context in which packet is communicating, location, energy and provider nodes. Congestion control forwarding mitigates the congestion in the network which is caused by flooding.

### *A. Adaptive Forwarding*

In [14] author builds an intelligent and adaptive data forwarding plane. Adaptive forwarding ensures the retrieval of DATA packets trough the best possible path and emphasizes the performance as well. It detects any possible problem, like congestion, during the forwarding process. A NACK field is introduced in this strategy. NACK will return to the downstream nodes in case of any problem in forwarding with the same name as that in the INTEREST packet, along with an error code explaining the reason for generating NACK (Congestion, No Path). PIT maintains a datagram forwarding state and creates entry against each name with incoming and outgoing interfaces. FIB entry contains a ranked list of multiple interfaces and routing information of adaptive forwarding decisions. A simple coloring scheme is used in this adaptive forwarding. When a new FIB entry is created, the interface status becomes yellow; it turns green if DATA is currently flowing back from that interface; if RTT times out with pending Interest, it turns yellow; and it turns red if NACK is received in case of failure. FIB entry is ranked to select the forwarding strategy according to the situation. The one-to-one flow balance between INTERESTs and DATA helps in congestion control. Retransmitted and new INTERESTs, proactive interface probing, and INTEREST NACKs are discussed in adaptive forwarding.

In case of no PIT entry for a newly arrived INTEREST, the router creates a new PIT entry and forwards the INTEREST using the highest ranked available green interface for the name prefix, otherwise the yellow interface is used. In other cases, if INTEREST matches in PIT but nonce does not, then INTEREST is regarded as a retransmission. The forwarding router explores alternative interfaces whenever a NACK is received until it succeeds or until the timer expires, which then sets to explore an alternative path. Probing yellow interfaces in context of working paths or paths with better performance are also important. Probing offers performance and availability of information for substitute paths and retrieves duplicate data as well. Adaptive forwarding can be entertaining congestion control, link failure, and prefix hijack issues.

Stochastic Adaptive Forwarding (SAF) [15] is a newly purposed forwarding strategy that emulates a self-controlled water pipe system, distributing and guiding INTERESTs intelligently through the network and avoiding bottlenecks and link failure. Overpressure does the work to enable the congested nodes and separately lower the pressure. Decrease in the proportion of forwarded traffic through congested nodes is ensured through an implicit feedback mechanism. SAF outperforms recent strategies by enhancing the INTEREST satisfaction ratio. Local environments are explored by the SAF by redirecting requests that are likely dropped.

Probability aware forwarding (PAF) in [71] is another adaptive forwarding strategy that optimize Ant Colony optimization in context of NDN. A face is probabilistically selected to forward the packet. INTEREST and DATA used to probe the performance of faces (e.g., delay). Through this method, delay minimization and automatic load balancing are achieved. A statistical model is used for packet transmission that adaptively changed by the network conditions.

Adaptive forwarding based link recovery for mobility support (AFIRM) in [72] is an adaptive forwarding based forwarding strategy that addresses the challenges of data availability and mobility. AFIRM is a fully distributed, adaptive and content driven algorithm for NDN architecture. AFIRM reduces the packet loss caused by the Producers mobility.

In [73] an adaptive and holistic forwarding strategy uses the metrics like delay, bandwidth, load and reliability. Reliability metrics defines reliability and stability to get legitimate data. Proposed forwarding strategy in [73] enables reliable message delivery.

### B. Blind Forwarding

Flooding is the most simple and easiest way to send the INTEREST packet in a wireless scheme. Flooding helps in sharing the content in the network. In flooding, one node can inspect the data of an incoming INTEREST from any node without any explicit request, which results in lesser number of transmissions and energy control. To get rid of broadcast storm, flooding must be handled very carefully. Distributed packet development mechanisms and techniques are present in the literature to control packet collisions and redundancy. We can implement slotted random, distance-based, or purely random defer schemes.

Blind and controlled flooding did not confirm that there is no packet collision or packet redundancy. Blind forwarding creates a broadcast storm issue in control. However, packet collision is still a problem that cannot be handled in blind forwarding. Aware forwarding techniques are used to avoid these problems [16].

A timer-based packet suppression strategy is discussed in [81] for improvement in packet delivery performance. The idea behind this technique is to drop the overheard same packet in the channel. Topology based routing is preferred over keeping per-neighbor state. While CCVN [82] is also a blind forwarding technique. It supports VANET, particularly.

### C. Aware Forwarding

Aware forwarding can be further classified into different categories. This categorization depends on next hop, neighborhood, location, and distance.

1. Next-hop Aware Forwarding
2. Provider Aware Forwarding
3. Neighbor Aware forwarding
4. Geo Aware Forwarding

In Next-hop aware forwarding, Interest is broadcast towards the next hop and the farthest node is selected as a relay node. In neighbor aware forwarding, a node communicates with other neighbors nodes by considering their current status. Duplicate messages and flooding can be control using neighbor aware forwarding. In Provider aware forwarding, a Consumer obtains content from more than one source. Therefore, the selection is based on the best content retrieval performance of the Provider. Geo aware are direction-selective forwarding schemes which are proposed for packet forwarding.

*1) Next Hop Aware:* In [17], Consumer broadcasts the INTEREST in direction-selective forwarding to its one hop neighbors, and the node that is farthest selected as a relay node in each quadrant. Two additive packets (CMD, ACK) are interchanged hop by hop between the sender and nodes that are intermediate forwarders and their neighbors.

The Greedy Ant Colony Forwarding (GACF) [18] algorithm uses two kinds of ants to progress all routing and forwarding optimization. INTEREST and DATA ants are the packets that are used. Two kinds of packet are used to collect the forwarding and routing information on receipt of data—normal packets, produced by the Consumer, and Hello packets, produced by the router. Hello packets are responsible for optimizing and routing the path for Normal packets. Next-hop selection is done by the ants, using the greedy approach. Next-hop is probabilistically selected by the Hello ant that purposes that the current network state is updated and new paths can be found. GACF is a QoS aware forwarding algorithm that reduces the influence of network congestion, link failure, and dynamic network topology adaptively.

*2) Provider Aware Forwarding:* PAF [19] is mainly based on Distance aware forwarding techniques, like LFBL and E-CHANET [21] protocols. If a Consumer obtains content from more than one source, then the selection is based on the best performance Provider. The mechanism is to send an allow command to one Provider in case there is more than one Provider. After receipt of the allow command, the Provider sends a reply to the Consumer. The Consumer will reply to one best Provider, if the replies are from more than one source.

Listen first broadcast later (LFBL) [19] is a forwarding strategy that was conceived originally for the multihop wireless networks with data centric addressing, without typically used NDN architecture that includes three kinds of tables—PIT, CS, and FIB. There are no PIT, FIB, and CS tables in the proposed design of the forwarding strategy. The only required data structure called DT (Distance Table) is used in the design that keeps the information of distance between communication end nodes and each node participating in communication. Three packet types, that is, REQ, REP, and ACK are leveraged by the LFBL. Content request (REQ) is used as INTEREST packet while content response (REP) is used as DATA packet. Provider selection is confirmed by the acknowledgement (ACK) field. The data retrieval process begins from the controlled flooding of the REQ, which discovers all available Provider(s). The ACK packet is sent to confirm the Provider. After this the distance-based forwarding strategy is enabled to decide the forwarding by checking DT by each intermediate node. The LFBL communication mechanism is presented in Fig. 7.

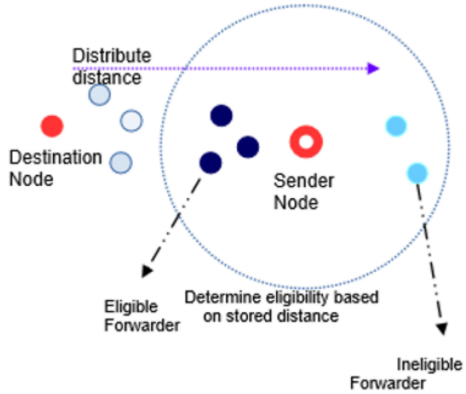


Fig. 7. Listen first, Broadcast Later [19].

Tactical MANET CCN [20] services two types of routing schemes: (1) content pushing and (2) content pulling. An INTEREST that includes content name is sent by the node to the gateways of the domain and its neighbors to obtain data. When that INTEREST has been received to the node where DATA has been transmitted, the node searches its content source and discards the packet after spreading the content packets using the same interface from where the INTEREST arrived. The node checks its INTEREST table, which keeps a record of all communicating INTERESTs, in case of no matched data. In another case, metadata registry will look up and match entry results in the re-broadcast of the INTEREST. If there is no matched entry in the metadata registry, then the DATA is forwarded towards its domain gateway. The information related to relayed packet that includes arrived interface and transmitted interface is written in the INTEREST table. The same path is followed as the requested DATA. MANET CCN has a packet collision avoidance mechanism that employs control packets.

E-CHANET [21] is also a proposed Provider aware forwarding strategy. E-CHANET targets the issues of channel unreliability, dynamic network topologies, and broadcast storm mitigation, while also focusing on the reliability, energy, efficiency, and Interest rate control. A counter-based suppression mechanism is used for packet forwarding that reduces the probability of packet collision and also limits broadcast storm. Three additional fields are extended in INTEREST packet format, in which the hop count contains the number of hops traversed, sProvID contains Provider ID, and Dp contains distance matrices from Consumer to Provider. Four additional fields are also present in the DATA packet hop count, just as in the INTEREST packet, Rate info updates the transmission rate, ProvID contains the ID of Provider nodes, and DC contains the distance record of distance to Consumer node. In E-CHANETs routing and forwarding process, there are three phases involved: Controlled flooding of INTEREST packets, soft-state PIT entries handling DATA packet forwarding, and INTEREST packet forwarding driven by soft-state CPT entries.

CHANET [22] is a content-centric MANET that is built on the top of the IEEE 802.11 with a connectionless layer design. CHANET provides routing and transport based on content without taking IP into account. To cope with topology variations and high mobility, CHANET relies on content names rather than source and destination IP addresses. Simplicity, robustness, and availability are ensured because of the broadcasting packets. Overhead packets in CHANET give it an advantage of resolving collision and scalability issues. At each receiving node, forwarding decisions are taken without any clear and explicit exchange of signals with neighbor nodes. Sequence control and retransmissions are implemented in this mechanism. There are a few techniques that are implemented in the CHANET for Consumer and Provider mobility.

Mobile CCN [23] is a basic proactive scheme in which the Provider node broadcasts the name prefixes; thereafter any of the nodes maintain FIB. Intermediate nodes broadcast the INTEREST request to all nodes till the content is matched by the Provider and comes back from where it requested. This scheme can be good for small area content delivery.

*3) Neighbor Aware Forwarding:* NAIF [24] is an adaptive propagation mechanism that maintains robustness and reduces the overhead of flooding. All transmissions in NAIF are broadcast. Congestion and collision problems can be created if senders are hidden from each other and send identical packets. NAIF controls the transmission and mitigates superfluous forwarding by hidden terminals. NAIF also controls the forwarding rate. If a node hears the neighbor nodes sending DATA packets corresponding to the INTEREST packets it dropped, it will lower its forwarding rate. There is an increase in forwarding rate if a node detects that it dropped too many INTEREST packets. In this manner, collision and congestion can be handled.

BlooGo [25], a gossip algorithm takes minimum number of transmissions to deliver messages all over the network. In a troubled network, the gossip algorithm opens up an effective and robust way to deliver messages. Node-to-node forwarding mechanism is used until they reach their destination. BlooGo can be used in sensor environments as well as in MANETs. An application can competently send messages from one host to many by adopting BlooGo. BlooGo is ideal for embedded and sensor environments because it is valuable when a packet does not have information regarding the destination. Every time it compares two bloom filters and uses only arithmetic operation, it reduces energy usage and lessens the number of transmissions. In BlooGO, the intermediate node takes the forwarding decision based on a comparison of the neighborhoods of the receiver and sender. To ensure that there is no redundancy, the packet is forwarded to that neighbor node that is not involved in one-hop advertising.

Multipath Ad-hoc Data Network (MADN) [26] for ad hoc wireless content distribution is a clean slate protocol. MADN encourages multi-path DATA delivery and seamless route redundancy. In a wireless medium, to take benefits of multi-source DATA delivery and balance the packet loss, MADN uses rateless encoded DATA packets. MADN uses the BlooGo algorithm [25], which gives the advantage of less hop travelling during DATA delivery and maintains other routes enabled as back of shortest. MADN is also a neighbor aware forwarding technique.

TOP-CCN [27] is a neighbor aware forwarding strategy that is designed to cope with the problem of broadcast storm and to enhance the content delivery stability in MANETs. Proactive MANET routing protocol is used to ensure the efficient and robust discovery of content. A content announcement (CA) packet is periodically broadcast by every node in TOP-CCN that contains the neighbor and senders prefix information. To improve the precision of face information, every node occasionally updates its FIB table, including 1-hop and 2-hop neighbor information. Three noel algorithms, MPR, PMPR, and flooding range control are used by TOP-CCN to reduce packet flooding. There are three extended fields in both INTEREST and DATA packets of TOP-CCN. An ID field that depicts the unique id of Consumer and sender as well as the distance between Consumer and Provider is stored in expected hop, and hop count keeps the count of hops travelled by the packets. Expected hop is also updated by the relay node and sender to reduce the flooding range. Two tables are defined in TOP-CCN, 1-hop neighbor, and 2-hop neighbor to ensure stable content delivery and discovery. To reduce congestion and collision problems, TOP-CCN selects a set of MPR that can feast its received packets. MPR also selects to mitigate the overhead of packet flooding. Packets are flooded for content delivery and requests using FIB and PIT. Through limited INTEREST packet and content packet flooding, the performance of TOP-CCN is decreased using the flooding range control algorithm. TOP-CCN provides the benefit of highest content availability.

BOND [28] is a proposed forwarding scheme for mobile devices. Forwarding state is maintained by the BOND header in each DATA packet. When a node receives a packet, then the forwarding state is updated. This shows the nodes that take part in the communication, without any clear path set up; coordination can be the potential forwarders at any time. The receiver side is responsible for all the forwarding decisions in BOND. The sender simply broadcasts the INTEREST toward the neighbor nodes. When an INTEREST packet is received at the node, then the node decides whether it is an eligible forwarder or whether it can be helpful to forward the packet toward the destination. If yes, then it waits for some amount of time, which is known as listening time, in which it overhears its surrounding to determine if any of the nodes are forwarding the same packet. If not, then it will forward the packet further. In short, two types of decision-making take place in BOND:

1. Selection of eligible forwarder
2. Waiting time to listen to the channel

*4) Geo Aware Forwarding:* A direction-selective forwarding scheme [17] proposed for packet forwarding, in which a sender decides the forwarding strategy. The sender node divides the plane into four equal quadrants and then forwards the INTEREST to one of the hope neighbor nodes. Before sending ACK, neighbor nodes check all the duplicate requests and while sending the ACK, make the duplication count 1 and send the DATA ACK back to the sender in the same fashion.

Best Route, Error Broadcast (BREB) [29] is another forwarding technique in wireless ad hoc MANETs. BREB defines two types of packets: INTEREST and DATA. Each node in BREB maintains PRT (Pending Request Table) and CPT (Content Provider) along with TTL, in which Distance and Provider ID fields are presented. Unsatisfied requests are recorded by the PRT, while CPT holds the information of responsive Providers. The basic communication process of BREB [29] includes three phases:

1. Content discovery
2. Best route interaction
3. Dynamic routing adjustment

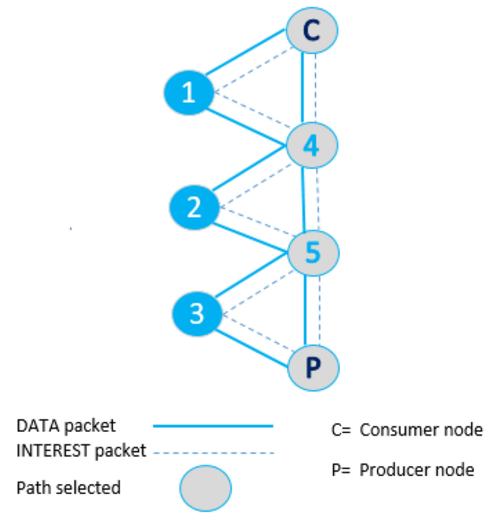


Fig. 8. BREB [29].

BREB uses the shortest path, through which signaling overhead can be lessened. In case of a breakdown in the shortest path, sub optimals are taken as alternatives. Fault recovery mechanism is also present in BREB. Once an INTEREST packet is sent as a request, it is flooded toward all the nodes with Provider-ID set to a specific value and TTL field zero. If a node receives a packet, its TTL field will increase by 1. Maximum number of hops are also considered to cope with a broadcast storm problem. Once a packet has received any intermediate node, it checks the CPT and PRT table for the entry. If DATA is found, then information of INTEREST header and PIT will be put into DATA header. TTL value is set as distance in DATA and Provider ID is put into Provider ID fields. Thereafter, this real DATA value is inserted. DATA packet follows the same reverse path when it forwards back.

When DATA receives, it checks the content store first. It will discard the packet in case of existence of a copy there. Then PRT will be checked and packet will be discarded with no entry there. The value of TTL will be increased and forwarded to next hope until the Consumer is reached. The Consumer obtains some knowledge regarding the responsive content Provider, and when it receives the content request it is transmitted to the best path according to the distance measurement. There will be the possibility of INTEREST propagation from many paths like C-1-2-3-P and C-4-5-P. BREB selects the second one because it will be the best one. BREB promotes the best path and error free broadcasting. The forwarding mechanism is presented in Fig. 8.

Location-aware on-demand multipath caching and forwarding (LOMCF) [30] is a novel proposed forwarding strategy for

NDN-based MANETs. LOMCF is an on-demand and reactive forwarding mechanism that considers the current location of the node in the process of packet forwarding. Content retrieval time is mitigated and reliability of the packets increased by the LOMCF by using multipath forwarding techniques. A caching policy is also included in this scheme that reduces the duplication of the packets by using distance matrices. The node will forward the packet towards the Producer or Consumer only if it is at a lower distance from them. It will reduce the impact of unnecessary packet flooding. The node's remaining energy is also considered to enhance the performance of the entire network. Timer-based forwarding in LOMCF reduces the packet collision probability.

### D. Energy Efficient Forwarding

In MANET, the entities take part in communication are energy constrained like Laptops and mobile phones. In energy efficient forwarding strategies, there are mechanisms to reduce the energy consumption of the participating nodes that enhance the network efficiency.

REMIF [31] is a newly proposed novel scheme for NDN-based MANETs. REMIF, by reducing the flooding of INTEREST packets, increases network efficiency. Residual energy of active NDN nodes is also considered in this scheme and INTEREST message forwarding mechanism rely on nodes energy status. According to the mechanism of REMIF, a sender sends an INTEREST packet with the name of the content. After receiving the INTEREST, the Receiver node first identifies whether the packet is expired or replicated. The packet is dropped in case it is an expired or replicated INTEREST packet. If not, it further inspects the Content Store for data availability and node delay for defer time if data found. It will discard the transmission if it receives the same data in return in that delay time. Otherwise, it sends the DATA packet back to the requesting Consumer node. After CS and PIT entry checks, if no entry is found in any of CS and PIT, then the relay NDN node examines the energy of the message with a threshold of 13 percent. Energy below this results in an update of PIT data structure and termination of transmission, while energy above the threshold leads to the node listening to the channel for a delay time. If same DATA and INTEREST packet is received, then it terminates both the PIT data structure and the packet or INTEREST message transmission. A brief performance comparison with E-CHANET [21] is also described in the paper, which gives the outclass results of REMIF compare to other techniques.

To improve the performance of mobile cloud computing, an energy-efficient content retrieval scheme proposed in [17]. This proposed scheme is an enhancement in energy efficiency and scalability in MANETs at a large scale. For this purpose, a direction-selective forwarding scheme is used.

On-demand Energy-based Forwarding Strategy for Named Data Wireless Ad Hoc Networks OEFS [32] is a protocol that considers the nodes remaining and residual energy status during its communication process. Two type of packets are involved in this protocol. Each nodes data structure consists of content store, where data is present and Interest information table. OESF is a reactive technique, because there is no FIB in this approach. OEFS protocol does not use any additional control packet or data structure. When a node receives an INTEREST packet and the node is in a danger condition, it does not forward that INTEREST packet and focuses on maintaining its PIT by sending messages to the neighbors that result in increasing life time while reducing packet flooding. In this approach, collision detection is also handled in a manner that a node will overhear the packet from some other nodes within a specific time, in case of same type of message reception, and it will discard its own message entry to cope with collision problem and redundancy.

When a node receives a packet, it checks whether it is an INTEREST packet. After a Yes call, it first checks its nonce lifetime value in context of duplication and expired packet. Node will discard the message when node finds that it is duplicated or expired. Node will then check its content store, and if DATA is found, then node will overhear other DATA packets from around the nodes. If the same DATA packet is received in a specific time, node will discard its own packet. Otherwise, it will forward the packet after removing the entry from PIT. In another case, if the DATA packet is not in the content store, PIT will be checked and if found then residual energy will be examined. If DATA packet is in danger state, node will discard it and forward it in safe state. When DATA packet is received, node will verify that again, and check the PIT for that DATA packet entry, and if there is no DATA packet entry, it will be discarded. DATA packet is forwarded to other nodes in case of same packet received, while hearing the channel again.

### E. Congestion Control Forwarding

Congestion Detection based on RTO due to connectionless and multi-sources features of transport is not reliable in NDN. Congestion Detection, based on duplicate ACKs in NDN is not suitable because the receiver does not have any information of packet loss through duplicate ACKs. It is the receiver's responsibility to propagate and re-forward the loss INTEREST. The rate control single congestion control window-based mechanism is also not appropriate in NDN. The self-locking mechanism can create a fairness problem between unpopular and popular content. Flow control capability at receiver end, one INTEREST one DATA mechanism, and receiver pull-driven NDN transport mechanism encourages the controlled DATA traffic. Therefore, the congestion contributes among DATA packets. In NDN, congestion control can be handled by intermediate nodes, because each intermediate node maintains a packet table along with acknowledgement. Thus, the node itself controls the congestion problem [33]. In Receiver-based congestion control mechanism, the congestion can be controlled by the control of DATA rate at the receiver's end by limiting the sending rate. The receiver-driven mode of NDN helps in getting this control.

SIRC [34] is a purposed method that deals with this problem by adjusting and implementing the inter INTEREST gap. Single-source and multi-source algorithms support this receiver-based control mechanism. To cope with the multi-source problem, explicit control algorithms are proposed. In

NDN, explicit control algorithms send congestion information immediately when it crosses the limit of congestion. Another method is through a control signal packet, like NACK. The special control packet or the marked packet called NACK forwards toward the receiver end. It maintains a congestion update when it passes each node by comparing the congestion level in node and NACK. Congestion Control Scheme (CCS) is a scheme that uses the same fashion of control signal, and in this mechanism a receiver utilizes the Additive Increase Additive Decrease (AIAD) algorithm. In the AIAD algorithm, the receiver controls the rate of sending packets.

Hop-by-hop INTEREST shaping mechanism [35] is completely different from earlier. In this, each intermediate node maintains the forwarding rate and detects the congestion by limiting and controlling the transfer rate. HoBHIS controls the transfer rate according to the queue length of chunks. The hop-by-hop congestion control made it a very promising research direction, because it adapts to multi-source features and connectionless of the NDN network transport.

Hop-by-hop and Receiver-Driven INTEREST Control Protocol (HR-ICP) [36] in which Intermediate nodes compare the INTEREST rate and its related DATA Rate and Chunk-switched Hop Pull Control Protocol (CHoPCoP) [37] in which intermediate nodes observe and detect the outgoing DATA queue length and inform are some proposed schemes for hybrid control mechanism.

Packet Loss Avoidance in Content Centric Mobile Ad hoc Networks [38] is a proposed scheme that deals with the avoidance of packet loss in MANETs. On arrival of INTEREST packet, a node first check its cache. In case of no matched DATA in cache, it then searches its FIB for next hop selection with minimum hop count. In case of unavailability of hop count, it will find alternative nodes. If all alternative nodes are unavailable, then it will broadcast the packet. In such a situation, when the intermediate node changes its location, it will cause the loss of both INTEREST and DATA packets. The proposed scheme copes with this problem by finding alternatives and then broadcasting. Client will get the DATA, if the intermediate node will not move two hops away from its preceding node. If it will more than two, then node will get the DATA from other nodes nearby. Forwarding strategies in NDN based MANET are summarized comprehensively in Table II.

### *F. Comparative Analysis*

As we discussed earlier in our forwarding section that, In Next-hop aware forwarding, Interest is broadcast towards the next hop and the farthest node is selected as a relay node. GACF [18] reduces the network congestion and link failure that also optimize the QoS. SAF [15], PAF [71], AFIRM [72] and RAF [73] are adaptive forwarding strategies that changes its path with the network requirment very efficiently. AFIRM and SAF are the best performing strategies among all because of securing content and reducing number of packet transmissions efficiently.

In neighbor aware forwarding, a node communicates with other neighbors nodes by considering their current status. Duplicate messages and flooding can be control using neighbor aware forwarding. In our survey paper we discussed all neighbor aware forwarding strategies in NDN to our best of knowledge. A lot of work has been done in year 2012 and 2013 in NDN based neighbor aware forwarding schemes. All schemes adopt the methods to forward the packet efficiently using neighbor nodes. BOND [28] and MADN [26] choose the methods to reduce the number of hops to travel and select the eligible forwarding methods. BlooGo [25] forwarded the packet hop by hop for getting results in robustness and less data redundancy while TOP-CCN [27] forwarded the packet in 1 or 2-hop neighbors to control the congestion and the broadcast storm. NAIF [24] is producing best results by specifying the DATA retrieval rate and efficient selection of eligible forwarder. NAIF significantly reduces the flooding overhead as well as enhance the robustness.

In Provider aware forwarding, a Consumer obtains content from more than one source. Therefore, the selection is based on the best content retrieval performance of the Provider. LFBL [19] was the first work in provider aware forwarding that provide seamless mobility. After that Tactical MANET CCN [20] and CHANET [22] were the proposed schemes. In provider aware forwarding E-CHANET [21] was the best work proposed in 2013. Multipath forwarding and reduced nodes taking part in E-CHANET forwarding that enhance the performance of network, limit the energy consumption and network overhead and improve robustness and availability.

Geo aware are direction selective [17] forwarding schemes are proposed for packet forwarding. BREB [29] select the best route dynamically that reduces the signaling overhead and packet collision. LOMCF [30] compared to BREB is the best work in location and geo aware forwarding that consider the current location of the node and a caching scheme in LOMCF also reduce flooding, reduce packet collision and enhance network performance. In energy efficient forwarding strategies in MANET, a lot of work has been proposed in [17], [31], [32]. E-CHANET was the best performing scheme in terms of energy efficiency with provider aware forwarding mechanism. After that REMIF [31] was proposed to increase the energy efficiency that outperform the E-CHANET. OEFS [32] is the best work till date in energy efficient forwarding in NDN based MANET that reduce the data redundancy, reduce collision and improve energy efficiency. Congestion control forwarding strategies are also proposed in [34], [35], [36] that control the congestion in the network. Compared to all other forwarding schemes E-CHANET and LOMCF are the best forwarding strategies in NDN based MANETs.

## V. FORWARDING IN NDN BASED VEHICULAR AD HOC NETWORKS

Vehicular Ad Hoc Network (VANET) is a subfield and application that functions under Mobile Ad Hoc Network (MANET). VANET aims to guarantee the safety of driver, passengers and the entities around the environment. Comfort applications in VANET improve the comfort of passenger and efficiency of traffic as well as optimizes the route towards the destination. Exchange of safety elated information in safety

TABLE II
FORWARDING STRATEGIES IN NDN BASED MANETS

| Forwarding Strategies in NDN based MANETs | | | | | |
|---|---|---|---|---|---|
| **Forwarding Strategy** | **Type** | **Year** | **description** | **Benefit** | **Related Work** |
| Adaptive Forwarding | Adaptive | 2012 | Retrieve DATA via the best performing path(s). | Availability and better performance | [14] |
| SAF | Adaptive | 2016 | Distributing and guiding INTERESTs intelligently through network | Enhanced INTEREST satisfaction ratio | [15] |
| PAF | Adaptive | 2013 | Selectnext forwarding face probabilistically | Minimized delay Load balnacing | [71] |
| AFIRM | Adaptive | 2018 | Distribute,adaptive and content driven algorithm | Increase data availability support mobilty | [72] |
| RAF | Adaptive | 2016 | Use delay, bandwidth, load and reliability metrics | Enhanced reliabilit | [73] |
| Contrlled Flooding | Blind forwarding | 2015 | Inspection the DATA of an incoming INTEREST of any node without any explicit request | Simplest and easiest way to send INTEREST | [16] |
| Timer based | Blind forwarding | 2011 | Drop the packet if it overheard the same packet | Controlled flooding | [81] |
| Next hop awareness | Next hop aware | 2013 | Broadcasts the INTEREST to one hop neighbors and the node that is farthest selected as a relay node | Efficient Forwarding | [17] |
| GACF | Next hop aware | 2013 | Next hop selection is done by the ants using greedy approach | Reduce congestion, link failure | [18] |
| LFBL | Provider aware | 2010 | Three packet types REQ, REP and ACK leverages by the LFBL, Eligible forwarder | Provide seamless mobility | [19] |
| Tactical MANET CCN | Provider aware | 2010 | Services two types of routing schemes: (1) content pushing (2) content pulling | Packet collision avoidance | [20] |
| E-CHANET | Provider aware | 2013 | Reducing the number of nodestaking part, exploit the content sharing by multiple nodes | Enhanced performance, controlled scalability, limit overhead and energy consumption | [21] |
| CHANET | Provider aware | 2011 | CHANET provide routing and transport based on content | Simplicity, robustness and availability | [22] |
| Mobile CCN | Proactive and Provider aware | 2013 | Provider floods the name prefix,maintenance of FIB and,broadcastof INTEREST until match found | Good in small area content delivery | [23] |
| NAIF | Neighbor aware | 2013 | DATA retrieval rate for a specific name prefix and distance of node to the consumer decides the eligibility of relay node | Reducing the flooding overhead while maintaining the robustness | [24] |
| BlooGo | Neighbor aware | 2012 | Packets are forwarded from node to node until destination | Robustness and no packet redundancy | [25] |
| MADN | Neighbor aware | 2013 | Less hop travelling during DATA delivery and maintain other routes enabled as back of shortest | Multi-path DATA delivery and seamless route redundancy | [26] |
| TOP-CCN | Neighbor aware | 2013 | Content announcement (CA) packet is periodically broadcast, 1-hop and 2-hop neighbor tables | No Broadcast storm, congestion control | [27] |
| BOND | Neighbor aware | 2011 | Selection of eligible forwarder, waiting time to listen the channel | Efficient forwarding | [28] |
| Direction selective strategy | Geo aware | 2013 | Mechanism sender decides the forwarding | | [17] |
| BREB | Geo aware | 2017 | Three phases: content discovery, best route interaction and dynamic routing adjustment. | fault recovery, to avoid the high overhead of signaling | [29] |
| LOMCF | location aware | 2017 | Considers the current location of the node, A caching policy is also included | Reducepacket collision, enhanced networks | [30] |
| REMIF | Energy aware | 2016 | By reducing the flooding of INTEREST packets increases the network efficiency, examine the energy of message | Outperform E-CHANET and other | [31] |
| Energy efficient scheme for Mobile Cloud | Energy aware | 2013 | Used for the INTEREST forwarding | Enhance performance | [17] |
| OEFS | Energy aware | 2017 | Considers the nodes remaining and residual energy status | Less redundancy and collision | [32] |
| Receiver based, HoBHIS, HR-ICP, CHoPCoP, SIRC | Congestion aware | 2016, 2014, 2012, 2014 | INTEREST rate, forwarding rate maintenance, | Avoid congestion | [33][34] [35][36][37][38] |

applications of VANET increase the safety of driver, passenger as well as the environment around and efficiently deliver infotainment to vehicular users. In VANET environments, a vehicle can communicate with the RSU (road side unit) and neighboring vehicles. Sometimes, information from the source node is very critical (i.e., accident, road condition); thus, the communication between the source and destination nodes is very challenging [39].

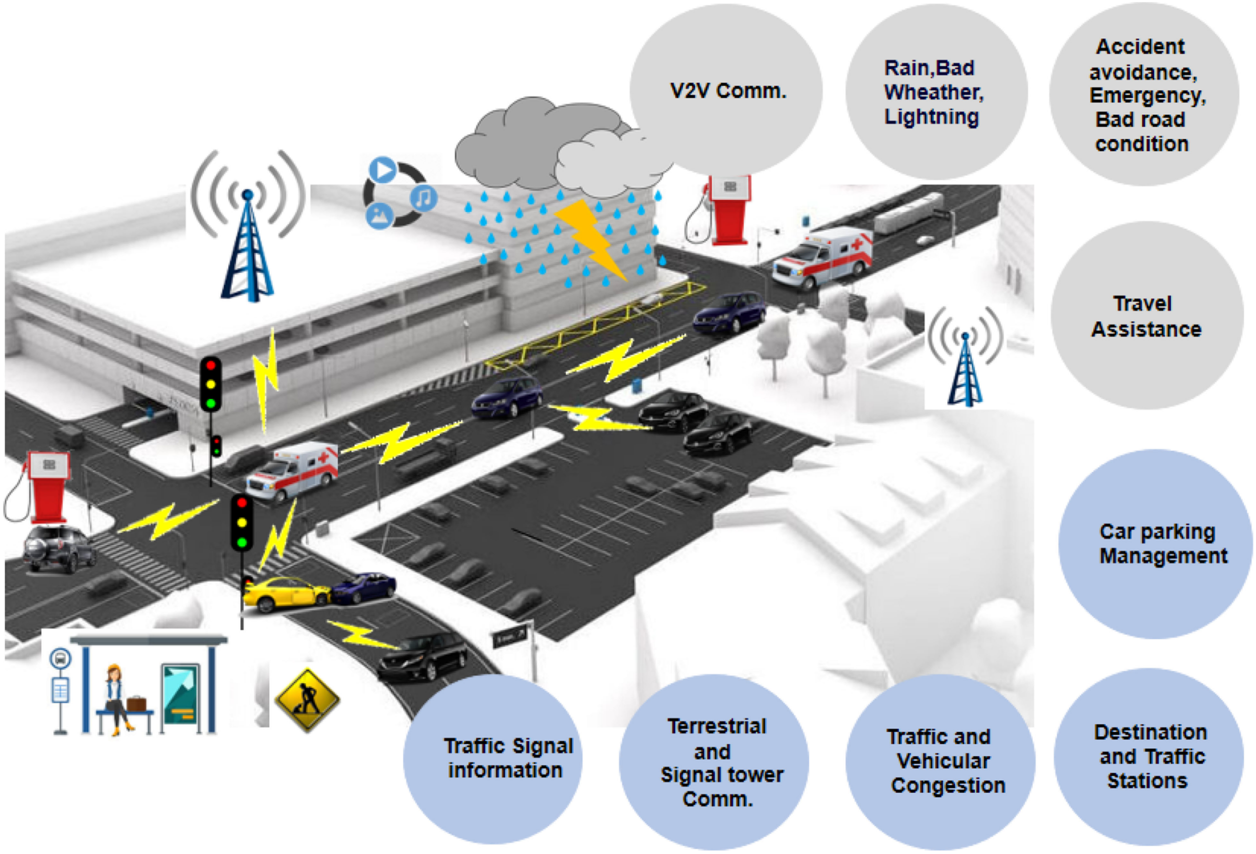


Fig. 9. Application scenarios in VANETs.

## A. Applying NDN to VANETs

We can achieve various benefits by applying NDN to VANETs. Information and messages are much more important for the user as compared to IP addresses. Thus, NDN brings a lot more for VANETs:

The information discovery and delivery are based on named data instead of the IP address. Multiple source nodes can be the Providers. Cache mechanism can make great contributions to decreasing end-to-end delay and network load. The named data can be cached in CS, which can be requested by other nodes. In particular, in a wireless VANETs environment, neighboring vehicles can overhear unsolicited information and store it in CS. Named DATA makes it possible to continue to transmit the information from the breakpoint, when the link breaks.

The NDN framework can be installed in addition to any type of network. It is easy to connect VANETs, Wi-fi, 3G, and 4G together with fewer changes. Obviously, upon receiving the INTEREST, a node will decide whether and where to forward it, according to its FIB in NDN. However, in a wireless VANETs environment, there is only one 802.11p interface in V2V communication, thereby implying that there is no FIB guiding the subsequent forwarding. Moreover, every forwarding process can be regarded as a broadcast. To broadcast an INTEREST to the potential Producers, the simplest solution is to merely flood the INTEREST. However, this will lead to the well-known broadcast storm problem. Therefore, a forwarding strategy is in demand to take the place of FIB to adapt the NDN architecture to a VANETs environment.

In VANETs, vehicles equipped with various information devices (e.g., GPS, sensors, etc.) can collect information about its own status and the surrounding environment. Moreover, it can publish the collecting information to the services requester [40]. Application scenarios presented in VANET communication are depicted in Fig. 9. When a segment of the road ahead falls into poor condition because of heavy rain, vehicles several kilometers away can obtain messages and make decision to choose another path. Vehicles can also download multimedia streams from other vehicles. The messages generated by the source vehicle is very important and in certain context, can be very critical, for example, accident warning.

On the road, the principal target should be on to provide safety regarding accident of vehicles. To prevent a user from an accident, VANET applications provide crash alerts, road problem alerts, and assimilate assistance along with deceleration warnings. Forewarning about crash notifications is more significant and should always be given to automobiles on time. Thus, VANET supplies back fit video game titles, TV, inter automobile communication, sharing of photographs, and video clips to help users. On the road, a traveler could obtain details that will enable him to use of maps, GPS plus limited information by time as well as space. Traffic management programs aim to decrease traveling time, energy consumption of cars, trucks, or emergency vehicles. They monitor urgent circumstances and provide the best routes for cars, trucks, and ambulances. Payment applications: In previous cases, it has been frequently noticed that there are very long queues on toll barriers along with auto parking payment assortment points. In VANET, the situation is totally programmed if a car or truck traverses a toll road as toll tax is automatically deducted. Forwarding strategies in VANET are presented in the following section and depicted in Fig. 10. Following are the forwarding strategies in NDN-based VANETs:

1. Location Aware Forwarding
2. Neighbor Aware Forwarding
3. Context Aware Forwarding
4. Flooding Based Forwarding
5. Link Stability Based Forwarding
6. Distance Aware Forwarding

In location aware forwarding, a vehicle needs information of its surroundings environment instead of parking area, current parking fee etc. Context aware forwarding emphasizes on trusted information communication in vehicles. High priority messages needs to send immediately and keep confidential. Flooding and distance aware forwarding are also techniques that benefits the VANET communication. In neighbor aware forwarding, a node communicates with other neighbors nodes by considering their current status. Link stability aware forwarding strategies take care of the strongest link of the forwarding path. Long duration of link and strong link signal from neighbor nodes help in finding the best forwarding path.

### B. Location Aware Forwarding

A Geographic Opportunistic Forwarding Strategy [41] for Vehicular Named data networking is proposed for mobile devices, particularly for vehicular devices. If we discuss the scenario of this forwarding strategy, a vehicle needs information on their surroundings rather often in the context of parking area, parking area space, current parking fee, and estimated available spaces in upcoming hours. Two scenarios can be created in this situation: First, an INTEREST packet is requested by the consumer vehicle with the geographical tagged name to Point of Interest (POI) information. Second, when the INTEREST packet reaches the requested destination with the desired DATA, then a DATA packet is generated and forwarded to the consumer.

The Geographical Opportunistic Forwarding Protocol (GOFP) handles both the scenarios. INTEREST packets are requested to the POI by selecting the best relay nodes, and the nearest and most promptly responding vehicle can be taken as the best relay node. An INTEREST packet is forwarded to the moving relay node and that relay node finds another to propagate the INTEREST toward POI. A DATA packet is forwarded back in same fashion, by selecting the trajectory of devices and moving the device that is closer to the requester node or covering the distance faster to reach that requester vehicle. After receiving the DATA packet, the message validation process begins. CS checks and PIT updates are further steps.

Forwarding strategy describes in [42] attempts to achieve both efficiency and reliability for packet delivery in urban VANET scenarios. DATA packets follow the reverse forwarding path of INTEREST packets in NDN. INTEREST forwarding plays a more important role and needs more elaborate designs. By applying the naming scheme and the neighbor information exchange mechanism described above, each vehicle knows its neighbor's position and the position of the DATA source for any specific INTEREST, so the best next hop forwarder can be selected for efficient INTEREST delivery. However, neighbor information may be outdated, and wireless communication is unreliable, so the selected vehicle may not receive the forwarded INTEREST. Therefore, to improve reliability, any vehicle that receives an INTEREST makes its own decisions on whether to forward the INTEREST, even if the vehicle is not the indicated forwarder. This forwarding strategy comprises two parts: forwarder selection and forwarding decision. NAVIGO [43] is also a geo-aware mechanism that divides the world into different parts for packet forwarding.

HVNDN [44] is a mechanism proposed for NDN VANETs and is a probabilistic and opportunistic forwarding strategy that is proposed to address the issue of multihop forwarding in VANETs, which suffer from intermittent and short-lived connectivity and rapidly changing topologies. The HVNDN strategy is based on location-independent as well as location-dependent information. Because of its network and multisource caching, NDN has the advantage of overcoming these discussed problems and challenges. In the wireless environment, INTEREST and DATA packets, proposed in NDN, are usually flooded because of the absence of a Forwarding Information Base (FIB). More specifically, HVNDN presents a probabilistic and opportunistic forwarding approach for location-independent and location-dependent information, respectively, which takes full advantage of geographic information and the characteristics of Named Data in VANETs. To make Vehicle-to-Vehicle (V2V) communication more effective and reliable, retransmission and acknowledgement mechanism are presented in HVNDN.

HVNDN [44] inherits two types of packets in NDN—INTEREST and DATA. Two kinds of INTEREST are defined: Location INTEREST for location-dependent DATA and Blind INTEREST for location-independent DATA. The only difference between the two INTERESTs is whether they contain the Destination coordinate field. The Destination coordinate field, INTEREST life time, LHC (Last Hop Coordinate) field for its next forwarding decision and ACKFlag in DATA is an acknowledgment to the matching INTEREST and are the main ingredients of the Packets. In the HVNDN scheme, every vehicle only maintains two data structures, CS and PIT. As usual, vehicles could achieve a practically infinite power and cache supply. Thus, it is reasonable to presume that CS will store all DATA the vehicle requests or overhears. In the same manner, PIT keeps the track of the forwarded INTEREST. The forwarding scheme in HVNDN replaces the function of FIB in the original NDN. In the Forwarding Scheme under location-dependent DATA, since the consumer knows about the location of the Producer, which carries the desired DATA, the principle of INTEREST forwarding is to forward it to the location of the Producer as soon as possible, and then pull back the DATA. An opportunistic forwarding scheme for INTEREST and DATA,


Fig. 10. Forwarding strategies in NDN based VANETs.

which includes four procedures, INTEREST forwarding, carry and retransmit, DATA forwarding and DATA ACK. First, the consumer will broadcast a Location INTEREST containing the coordinate of the INTEREST location. Upon receiving an INTEREST, the intermediate node will get the LHC and Destination Coordinate information and perform the forwarding process after checking CS and updating the LHC. In a wireless VANETs environment, there may be situations that will lead to link break before the INTEREST arrives at the destination. If an intermediate node does not receive implicit acknowledgment after it forwards an INTEREST, it will carry and retransmit the INTEREST. DATA forwarding is performed in a reverse manner. DATA will be forwarded persistently if the PIT of a node matches. To avoid the waste of bandwidth, Consumer broadcasts DATA with the ACKflag field, which is valid to inform vehicles around to cancel the forwarding.

In Forwarding Scheme under Location-independent DATA, as the Consumer does not know the location of the Producer, the principle of INTEREST forwarding is to search for the potential producers first and then pull back the DATA. A probabilistic forwarding scheme for INTEREST to search the potential producers adequately includes four procedures: INTEREST forwarding, DATA forwarding, DATA ACK and INTEREST retransmission. DATA Forwarding and DATA ACK procedures are the same as location-dependent forwarding. The consumer will broadcast a Blind INTEREST, which does not contain the Destination coordinate field. Thus, vehicles A, B, and C will choose to participate in the forwarding first. Each node will check its CS and PIT. If these do not match, it will prepare to forward the INTEREST. Due to the problem of packet loss and control network load, velocity is used as a parameter. Before transmission, each node will choose a random delay to avoid collision with other nodes. As a result, the INTEREST will broadcast to two different directions along the road. As soon as a Producer receives the INTEREST, it will forward back the matching DATA. When the searching fails, which means that there is no Producer receiving and replying to the INTEREST or the link breaks, the Consumer will retransmit the INTEREST with a new nonce value. This proposed scheme is shown to outperform the R-NDN and flooding schemes both in end-to-end delay and overhead, which is important in VANETs.

A Reliable forwarding strategy for NDN VANETs proposed in [45], that sends the DATA towards its destination in less time as early as possible and ensures that there is no link breakage, while the packet of DATA travels back to its consumer node using the same reverse path. RFS use only beacons to share the information of neighboring nodes, and this practice enhances the performance of the entire network and reduces overhead. RFS is a lightweight and topology-free protocol.

A Location-Based and Information-Centric Architecture for Content Distribution (LoICen) in [74] is a location based forwarding strategy that increases availability of the requested content and reduces the broadcast storm. LoICen uses the NDN architecture. Location information of vehicle is opportunistically obtained in LoCIen having desired content information. This information used to improve the content search by INTEREST packet in area in which content is located.

LOCOS in [75] is a location-based content distribution protocol in NDN based VANET. LOCOS controls INTEREST packet transmission in the area where content source is frequently located. Broadcast storm is efficiently handeled through this forwarding strategy.

### C. Context Aware Forwarding

Context Aware Routing Protocol (CARP) [39] is presented for trusted information communication in vehicles. In VANETs, messages that are of high priority should be transmitted immediately to the vehicle and this needs more emphasis on trusting messages. CARP takes care of this mechanism and ensures the secure, reliable, and trusted transmission of the messages. In addition, CARP also ensure the transport of high priority messages in a trusted and highly secure environment. Applications Quality of Service (QoS) considered by the CARP makes this mechanism a highly efficient routing protocol. The protocol supports the NDN daemon, because it consists of NDN forwarding strategies and NDN data structures and includes the rules to investigate message trustworthiness.

CODIE [46] is a mechanism that is, proposed in VANETs to control DATA packet flooding in the VNDN. DATA packets are generally much larger than the INTEREST packet. The reason is that a DATA packet contains the actual DATA and, thus, is actually more likely to cause congestion. DATA flooding issue is handled by the CODIE by using hop count in INTEREST packets and an extra DDL field in DATA packet. Limitation of extra copies of DATA packets is the main goal of the CODIE. If a potential and possible Provider receives the transmitted INTEREST packet, then after moving the value of hop count in the DDL field, it sends the DATA toward the sink node. On arrival of the DATA packet on any node with a PIT entry corresponding to the DATA packet, the node will check its DDL field and the value of hop count in its PIT entry table. If the value of DDL is less or equal compared to the hop count value, then the node will forward the DATA further and decrement the DDL; however, if the DDL field is greater, then the node will discard the DATA packet. DATA packets are reduced by the CODIE.

CONET [47], is another forwarding strategy for conventional VNDN that controls the broadcast storm and data flooding. Consumer starts the hop counter in INTEREST, whenever a potential provider receives the INTEREST, provider will help to include TTL (time to live) value in DATA packet. Hop count will keep the record of traversed nodes. TTL value reduces the wrong and additional data dissemination with in the network. Upon INTEREST reception, intermediate node increments the TTL value and upon reception of DATA packet, intermediate node decrements the TTL value.

VNDN [51] proposes to take advantage of the wireless broadcast nature. Wi-Fi broadcast can suffer high losses due to collision. In terms of opportunistic forwarding, a simple set of mechanisms is presented in VANETs with support of Wi-Fi broadcast to enable resilient and efficient broadcasting. This Wi-Fi broadcast support is based on the packet forwarding weighted random wait scheme. Greedy forwarding strategy is used to propagate the INTEREST in all the directions with the assumption of GPS and digital map in each vehicle. Each INTEREST packet has the location information of its sender node. The farthest node from the sender will receive the INTEREST. The sender wants to know if the DATA is received for more forwarding process, otherwise it retransmits the INTEREST. In VNDN, a link adaption layer is used for this implementation with GPRS. Each node N in the link adaption layer calculates the distance of the sender with itself and sends a forwarder time (wait timer). The shorter the distance is the longer the forwarder time will be. If node N hears the INTEREST from another node without sender node, then it will backtrack and recognize that node.

Context-Aware Vehicular NDN (CA-VNDN) in [76] is a context aware data forwarding strategy in NDN-based VANETs. CA-VNDN reduces the total number of broadcasted INTERESTs and significantly increases the data delivery ratio. The strategy in [76] uses geo-position information and modifies the existing PIT for packet forwarding. Context aware algorithm in CA-VNDN considers network, environmental and content context surrounding the vehicle node with respect to the number of distributions and number of vehicles nearby. Irrespective of road condition, context aware algorithm maintains high performance in terms of data delivery.

### D. Neighbor Aware Forwarding

INTEREST Broadcast storm is an issue in communication between vehicles and other scenarios in VANETs. Robust Forwarder Selection (RUFS) [48] is a unique and robust scheme proposed to cope with the issues related to the broadcast storm. The main feature of the RUFS mechanism, or we can say the beauty of the RUFS, is the selection of only one forwarder that will be its immediate neighbor while waiting for ACK(s) for any INTEREST. RUFS allows each vehicle to maintain a neighboring satisfied INTERESTs list called Neighbor Satisfied List (NSL). In addition, it enables the vehicle to maintain a list of satisfied INTERESTs by itself, and this list is called the Recent Satisfied List (RSL). Each vehicle occasionally exchanges RSL with its neighbor vehicles to update the NSL information. In the RUFS mechanism, each vehicle is required to share its RSL periodically with all its immediate neighboring vehicles, so that the neighboring vehicles can update their NSL. Only those vehicles or nodes will select as forwarder that satisfies the content correctly and the forwarder will select with the max positivity. The Forwarder will forward the INTEREST in the same fashion and other nodes will discard that INTEREST. After INTEREST will meet the Provider, then the DATA packet will also return using the same path used by the INTEREST packet. The main goal of RUFS is to alleviate the INTEREST flooding issue. The key to success in RUFS is the reduction of forwarded INTEREST packet.

In Push-based data forwarding (PDF), [49] content is classified into two classes, Regular content class and Critical content class. Regular contents need regular updates and an INTEREST to forward the packet. The Critical content is generated at any time and generation of the Critical content is because of important events. In PDF, the Producer vehicle will collect the critical information regarding the safety of the driver and the misconducted activities of other vehicles. An additional field named object size is also included in the packet that contains content size and name.

Density-Aware Delay-Tolerant (DADT) [50] is an INTEREST forwarding strategy to retrieve traffic DATA in vehicular NDN with the purpose of improving the packet delivery ratio. The forwarding strategy includes two communication phases, rebroadcast and retransmission. Rebroadcast occurs immediately after a node receives an INTEREST packet. Retransmission occurs when a node stores the INTEREST packet for a while, after forwarding, and retransmits it. The rebroadcast nature of the nodes results in packet redundancy, packet collision due to INTEREST packet propagation from all nodes, and blind propagation along with unnecessary transmission. To deal with these discussed problems, DADT [50] sets up a defer timer for DATA transmission that reduces the collision issue. A higher priority node forwards the INTEREST. Priority will be set through the node that is the farthest from the last hop, and that will propagate the INTEREST in less time and fewer hops. In another approach, priority will set through the node that is closer to DATA location. In the second case, the chance of DATA forwarding is much more than the first one. VANETs can be categorized frequently. NDN suffers from low delivery ratio in the case of network interruption. DADT solves this issue, in which the node first stores the packet, then carries it, and thereafter retransmits it after a while. The node will retransmit the packet after identifying an appropriate neighbor node to forward the DATA. If the node hears another packet with the same name and a stronger forwarding case, then that node will discard its own packet from its retransmission pending queue that it had generated earlier, because of successful packet delivery. The transmission and retransmission queue is maintained by each node for transmission queue DATA and INTEREST. The node will update the queue after checking PIT and CS. The rebroadcast mechanism is used for DATA forwarding.

### *E. Link Stability Based Forwarding*

A Link-Stability-Based Interest-Forwarding (LSIF) in [79] is a link stability related forwarding strategy, that reduces the number of INTEREST by predicting the duration of the link.

A Link Stability-Based Protocol for Vehicular Information-Centric Networks (LISIC) in [80] is another link stability-based forwarding strategy in NDN-based VANET. It uses the mechanism to prioritize the neighbor vehicles with more stable link to forward the packets. LISIC tackles broadcast storm issue by controlling the INTEREST transmission.

### *F. Flooding Based Forwarding*

Epidemic, Spray n Wait, and Adaptive Forwarding are some of the flooding-based forwarding schemes [52] presented to explore the benefits of NDN in the wireless broadcast medium. Epidemic, Spray n Wait, and Adaptive Forwarding algorithms are implemented using the NDN and named as N-Epidemic, N-Spray, N-Wait, and N-Adaptive, respectively.

In N-Epidemic [52], vehicle broadcasts the INTEREST packets to all its neighbors. Neighbor that receives the INTEREST packet act as a relay node and the same process is repeated until the INTEREST packet reaches the valid carrier of the DATA. In VANETs, there is no need for the DATA packet to follow the INTEREST packet forwarding path in reverse. DATA packets follow the same forwarding scheme as INTEREST packets.

In N-Spray Wait [52], a vehicle forwards the INTEREST packet to the first N vehicles it encounters, and then these N vehicles carry the INTEREST packet till they obtain the corresponding content.

In N-Adaptive [52], when two vehicles meet, they check the state of the INTEREST packet to be forwarded in their PITs. If the state of the INTEREST packet does not exist in another vehicle, then the INTEREST packet is forwarded to another vehicle, otherwise it is not forwarded. These algorithms will work in a similar manner for push-based approach, except the return of the DATA.

### *G. Distance Aware Forwarding*

NVP [53] is a routing protocol based on NDN-VANET. As a distance matric, it uses the estimated link cost rather than hop counts. It also enhances the method of broadcast in VANETs. Density state of all vehicles that are present in the surrounding set are divided into different categories. Different packet forwarding techniques are used in every category. Broadcasting is different in VANETs and MANETs due to mobility, special traffic pattern, and topology. Two enhancements in broadcast strategy are offered in [53].

1. Incremental REQ broadcast
2. Adaptive broadcast strategy

Opportunistic Interest forwarding protocol (OIFP) in [77] is a distance-aware forwarding strategy to tackle with the broadcast storm issue in VANET. In OIFP, INTEREST priority towards the neighbor node and the distance between nodes are used to decide the forwarding path. OIFP uses current forwarder's location information and location of each neighbor, at each receiver to calculate the forwarding priority. Defer timer is used to handle the priority. By using the method, content delivery rate is improved and the number of transmissions of INTEREST packets is reduced.

Distance assisted Information dissemination with broadcast suppression (DASB) in [78] is a distance assisted forwarding strategy that minimizes broadcast storm. Acceleration of packet forwarding uses the geo-position data of vehicle. To avoid the broadcast storm, vehicle nodes are restricted to forward the packet in certain areas.

Forwarding strategies in NDN based VANETs are summarized comprehensively in table III.

### *H. Comparative Analysis*

In NDN-VANET we discussed the location-aware forwarding strategies that keeps the record of the location of the vehicle and other entities that take part in forwarding mechanism in VANET scenarios. Context aware forwarding strategies designed based on the actual context of the information.

TABLE III
FORWARDING STRATEGIES IN NDN BASED VANETS

| Forwarding Strategy | Type | Year | description | Benefit | Related Work |
|---|---|---|---|---|---|
| GOFP | Location aware | 2016 | INTEREST packets are requested to the POI by selecting best relay nodes, nearest and early responding vehicle can be taken as best relay node. | Validate and efficient DATA delivery | [41] |
| Geo-based forwarding strategy | Location aware | 2015 | Applying the naming scheme and the neighbor information exchange mechanism | Efficiency and reliability in urban VANETs | [42] |
| LoICen | Location aware | 2019 | Location information of vehicle is opportunistically obtained | Reduces broadcast storm | [74] |
| LOCOS | Location aware | 2018 | control the INTERST packet transmission | Broadcast storm is handled very efficiently | [75] |
| NAVIGO | Location aware | 2015 | Divide the world in different parts for packet forwarding. | Efficiency | [43] |
| HVNDN | Location aware | 2015 | HVNDN strategy based on location independent and location dependent information | Outperform the R-NDN and Flooding schemes both in,end-to-end delay and overhead | [44] |
| RFS | Location aware | 2016 | Sends the DATA towards its destination in less time as early as possible and make sure that there is no link breakage | Enhances the performance of whole network and reduce overhead | [45] |
| CARP | Context aware | 2015 | Ensure the transport of high priority messages in trusted and highly secure environment | Highly effective and efficient routing protocol | [39] |
| CODIE | Context aware | 2016 | DATA flooding issue is handled by the CODIE by using hop count in INTEREST packets and an extra DDL field in DATA packet | Control DATA packet flooding | [46] |
| CONET | Context aware | 2016 | DATA flooding issue is handled by the CONET by using hop count in INTEREST packets and an extra TTL field in DATA packet | Control DATA packet flooding | [47] |
| CA-VNDN | Context aware | 2018 | Use geo-position information and modify the existing PIT for packet forwarding | High DATA delivery, reduced broadcast storm | [76] |
| VNDN | Context aware | 2016 | Greedy forwarding strategy is used to propagate the INTEREST in all the directions with the assumption of GPS and digital map in each vehicle | Use advantage of wi-fi broadcast to mitigate collision | [51] |
| RUFS | Neighbor aware | 2015 | Selection of only one forwarder that will be its immediate neighbor with waiting for ACK(s) for any INTEREST, maintenance of NSL and RSL | Alleviate the INTEREST flooding issue, mitigate broadcast storm | [48] |
| PDF | Neighbor aware | 2016 | Content is classified in two classes. Regular content class and critical content class | In-time DATA retrieval | [49] |
| DADT | Neighbor aware | 2016 | Rebroadcast and retransmission | Increase in packet delivery ratio | [50] |
| N-Epidemic | Flooding based | 2017 | Vehicle broadcasts the INTEREST packets to all its neighbors | Efficient packet delivery | [52] |
| N-Spray& Wait | Flooding based | 2017 | Vehicle forwards the INTEREST packet to the first 'N' vehicle | Efficient packet delivery | [52] |
| N-Adaptive | Flooding based | 2017 | When two vehicles meet, they check the state of the INTEREST,packet to be forwarded in their PITs and then forward | Efficient forwarding | [52] |
| NVP | Distance aware | 2016 | Estimated link cost as a distance metric instead of hop counts, it optimizes the broadcast method according to the special feature of VANET | Support mobility | [53] |
| OIFP | Distance aware | 2017 | Distance between nodes and prioritized INTERESTs transmission between neighbor nodes decides the forwarding path | Content delivery rate is improved | [77] |
| DASB | Distance aware | 2016 | Vehicle nodes are restricted to forward the packet in certain areas where data located | avoid broadcast storm | [78] |
| LSIF | Link stability aware | 2018 | Predicting the duration of the link | Reduces the number of INTEREST | [79] |
| LISIC | Link stability aware | 2017 | Prioritize the neighbor vehicles with more stable | Avoid broadcast storm | [80] |

Neighbor aware forwarding strategies designed based on the performance of neighbor vehicles. Flooding based, and agent assisted forwarding strategies are also discussed in this survey paper.

A lot of work proposed in location-aware forwarding in year 2015. NAVIGO [43] was a good performing forwarding strategy that divides the world into four parts to enhance the forwarding and efficiency. RFS [39] send the packets in less time that enhance the performance of overall network. LoICen [74] and LOCOS [75] in 2019 and 2018 respectively, are also location aware strategies that controls the Interest forwarding towards the content location. This will control the Interest rate. GOFP [41] is the best performing scheme in location aware forwarding that takes the best relay node for efficient data delivery.

Context aware forwarding strategies in NDN based VANETs proposed in year 2015 and 2016. CODIE [46] and CONET [47] are the best performing forwarding strategies. CARP [39] is also best performing strategies that ensure the important and high priority message in trusted and highly secure environment. CA-VNDN [76], proposed in 2018 is also a context aware forwarding strategy

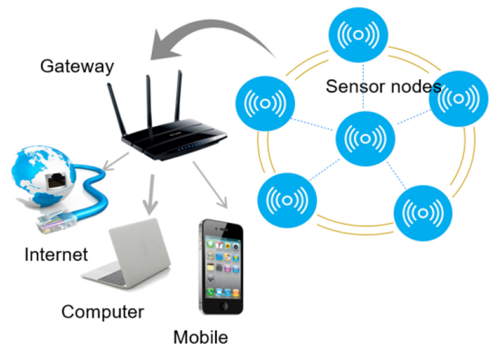


Fig. 11. Wireless Sensor Networks.

that increase the data delivery and reduce number of interests.

Neighbor aware forwarding strategies in NDN based VANET benefit the communication of packets by selecting the neighbor forwarder efficiently. RUFS [48], reduces the broadcast storm and flooding problem while DADT and PDF increase the efficiency in packet delivery. DADT [50] is the best performing neighbor aware forwarding scheme.

Forwarding strategies in [33] are the best performing flooding based forwarding strategies that enhance the packet delivery. NVP [53] is the best distance based forwarding strategy that support the mobility in efficient way. OIFP [77] and DASB [78] are also distance based forwarding strategies and perform very well to mitigate the broadcast storm problem. LSIF [79] and LISIC [80] are best link stability based forwarding mechenism proposed in 2018 and 2017 respectively. LSIF performing better in this scenario. CARP, NAVIGO and RUFS are the best performing strategies in NDN based VANETs.

## VI. Forwarding in NDN Based Wireless Sensor Networks

The main feature of wireless sensor network (WSN) is the lack of an infrastructure, which consist of untethered communication resource constrained devices [7]. WSNs are used for logistics, environmental monitoring, and surveillance-like tasks that need to connect with servers that are remote. In terms of memory, energy, and processing resources, sensor devices are most critical. Fig. 11 shows the WSNs architecture.

Forwarding strategies regarding NDN-based wireless sensor networks are presented in this section and summarized in Table IV.

In wireless sensor networks, the Basic NDN operation [54] is presented, in which NDN assumes that the INTEREST packet is forwarded over some network interfaces that are available instead of the sender node. In basic NDN, each sensor behaves like a single radio interface. First, the packet is forwarded over the interface that it comes from. INTEREST rebroadcast mechanism is used in this scenario to reduce the packet collision between INTEREST and DATA packets. This also reduces the redundancy of the packets. Rebroadcasting event on INTEREST and DATA packets are calculated in the deference window. A potential INTEREST forwarder then listens to the channel and if the forwarder overhears the same INTEREST from the channel, it will terminate it on transmission. The sink node will retransmit the INTEREST packet if there is no answer received in the given interval of time. This simple Basic NDN approach collects the data without any information on the sensor place and network topology.

Directed diffusion [55] is probably the first DATA-centric architecture for wireless sensor networks. A sink node sends a request for a task, called INTEREST packet toward the source node. The INTEREST-packet leaves breadcrumbs in the cache of every hop that it traverses while being propagated to the source node. When the node receives an INTEREST packet, it adds an entry in the cache or updates an existing entry. An existing entry indicates that a similar INTEREST has already traversed this node and probably has been propagated. Current node may decide to propagate such INTEREST to all or subset or none of the neighbors based on cache entry. By receiving the INTEREST packet, the source node will perform the task and send the DATA packets toward the sink node, using the breadcrumbs. A node that receives the DATA, will check the cache for entry of the INTEREST. If no such entry exists, it will drop the DATA packet. If such an entry exists, it will check the DATA cache. The existence of the same DATA in the DATA cache can be an indication of loop in the DATA path.

A Dual-mode Interest Forwarding Scheme (DMIF) [57] proposed for NDN-WSNs. Two combined forwarding modes involves in DMIF mechanism. Several mechanisms that are energy efficient including flooding scope control, packet suppression, flexible mode shift, broadcast storm avoidance, and factors related to energy weight are designed to balance and save the consumption of energy. Data naming is one of the most important technologies in the NDN architecture, which may affect the design of the INTEREST forwarding and routing. Three-dimensional naming, that is, time dimension, space dimension, and type dimension for the raw DATA in this application is prosed in the DMIF approach. Flooding is the simplest way to discover the potential content providers and the flow of DATA packets along the reverse paths, which can help find the content sources more quickly at less cost are some of the considerations behind DMIF. In DMIF, a content consumer checks the FIB at first before sending out an INTEREST packet. If the FIB lookup hits successfully, the INTEREST will be sent in the directive mode (DM). Otherwise, the INTEREST will be sent in the flooding mode (FM). An extended named field as Forwarder ID about the unique ID of the next hop forwarder is carried in the INTEREST packet to find a neighbor node as the forwarder of the INTEREST. A node receiving the INTEREST packet will check local content store CS and the node will perform INTEREST forwarding based on the proposed DMIF in case of lookup failure. The node should continue the INTEREST forwarding, if there are no duplicated INTERESTs received before, in case of presence in FM mode. If the incoming INTEREST is in DM mode and node is the same as earlier, then the node will perform the forwarding. In case of FIB lookup miss, the flooding mode (FM) is used to circulate the INTEREST packets. FM mode concentrates on how to implement controlled flooding to reduce energy consumption and improve discover efficiency. Scope

TABLE IV
FORWARDING STRATEGIES IN NDN BASED WSNS

| Forwarding Strategies in NDN based WSNs | | | | | |
|---|---|---|---|---|---|
| **Forwarding Strategy** | **Type** | **Year** | **description** | **Benefit** | **Related Work** |
| Basic NDN Operation | Basic NDN approach | 2013 | Basic NDN approach collect data without any information about the sensor place and network topology. | Reduce the packet collision | [54] |
| Directed diffusion | Diffusion based | | Interest packet is leaves breadcrumbs in the cache of every hop that ittraverses while being propagated to the source node | First data centric strategy for WSNs | [55] |
| DMIF | Energy aware | 2016 | Two combined forwarding modes are involving in DMIF mechanism, Directive and Flooding modes | Reduce consumption of energy, Flexible mode shift, broadcast storm avoidance | [57] |
| dd-NDN | Path Aware | 2015 | Path will likely last long that discovered,after the transmission, is used for further communication of packets, | Limit the collision and reduce the traffic overhead | [54] |
| Plain Vanilla | IOT based | 2016 | Simply broadcasts the Interest on the wireless, interfaces and nodes with matching content, replying with Data messages | Support push based forwarding of critical data, which can be any emergency sensed by sensors | [58] |
| SLICT | GEO aware | 2016 | Associate and discover the neighbors to ensure the packet communication only if the node is authorized and trusted, a safe beaconing protocol thathandles the location and topology changes | Secure forwarding | [59] |
| CCN-WSN | Named Based | 2013 | CCN-WSN for wireless sensor networks is lightweight CCN protocol to deliver the packets | Flexibility, Small area data transmission | [60] |
| GIF | Location aware | 2018 | Data naming, discovery of the neighbor, discovery of producer and exchange of the data are the basic modules of the scheme. | GIF reduces the broadcast storm by reducing the number of interests, reduce the packet drop and improve energy efficiency | [68] |

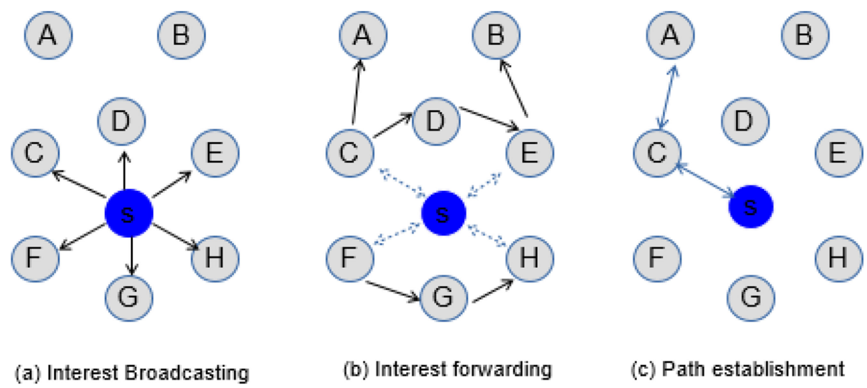


Fig. 12. Example of path establishment for dd-NDN.

control, broadcast storm avoidance, and packet suppression are the schemes to support controlled flooding. TTL (Time to Live) field is added into the INTEREST packet to control the distribution scope of an INTEREST. A deferred timer based on transmission distance and remainder energy is adopted in the INTEREST flooding in DMIF to avoid the effects of broadcast storm. Prefix, Forwarder ID, Hop, Energy, Timer is the field of FIB. To cope with the routing loop problem of the data forwarding, a new field named ID List in the DATA packet is introduced that contains the IDs of all nodes along the forwarding path. Node will check its ID in ID List, in case of YES, incoming DATA will be dropped and in case of NO, it updates the list. DMIF is only applicable for the INTEREST forwarding, DATA forwarding process is always the same. Performance of the DMIF scheme examine on the Total energy consumption, Energy equilibrium rate (EER), Hop count, and Network lifetime metrics.

An enhanced approach to cope with the difficulties in forwarding mechanisms of WSNs is called dd-NDN [54]. A path will likely last long that was discovered after the transmission of first INTEREST and reception of first DATA object and relevant DATA retrieving. This information regarding the path is used by the NDN forwarding strategy for the INTEREST packets are later sent. This will limit the collision and reduce the traffic overhead of the involving sensors in process of delivery. We will take an example of a better understanding of this enhanced dd-NDN [54] model as shown in Fig. 12. The starting node called Sink, broadcasts an INTEREST packet data/humidity/campus towards its entire neighbor nodes. In case of no requested DATA, INTEREST will rebroadcast after a specific defer time T. This defer time can be random. In this example node C, E, F, H grab and snatch the channel and transmit the packet further while the node D and G cancel their own transmission by receiving duplicate INTEREST packet from neighbor nodes. Node H and F finally discard their PIT entry because they did not receive any answer. Node C receives the DATA from the node A and includes it on the next hop table node for INTEREST packet data/humidity/campus and then forwards the packet.

The plain vanilla NDN forwarding architecture for smart cities [58], simply broadcasts the INTEREST on the wireless interfaces and nodes with matching content, replying with DATA packets. With many wireless devices, it is not feasible to simply broadcast the messages. Therefore, this element is responsible for reducing the message broadcast and forwarding the INTEREST/DATA packets according to the nodes directional or selective forwarding. Push-Based Forwarding involves in plain vanilla NDN. Any node that receives a DATA packet, first checks its PIT. If there is no PIT entry for the DATA packet, it is considered as unsolicited and dropped. To be precise, every producer requires an INTEREST packet from a consumer before it can send the required DATA packet. Even though, this mechanism hinders the retrieval of unsolicited DATA packets and secures an overall network from being overtake, the behavior of vanilla NDN is more consumer centric than content-centric. This proposed architecture will support push-based forwarding of critical DATA, which can be any emergency sensed by sensors.

In IOT deployments, SLICT [59] is a mechanism that performs secure forwarding based on geographic location. SLICT is the mechanism that associates and discovers the neighbors to ensure the packet communication only if the node is authorized and trusted. SLICT is a safe beaconing protocol that handles the location and topology changes. The naming scheme used in SLICT confirms independant INTEREST forwarding over the network in geographic forwarding. SLICT [59] considers a forwarding framework that performs the in ICN based WSNs. Most of the geographical mechanisms are based on the greedy approach of forwarding.

A greedy forwarding-based geographic forwarding mechanism is presented that is not available in today's advance tool kits like Contiki and RIOT. Perimeter routing technique is used by the GPSR to avoid the local maxima. In this technique packet need to carry the coordinates of the node where the packet entered the perimeter mode. There is a field in SLICT called TLV (Type length value) in which SLICT store the coordinates information and flag determines, whether GPSR is in perimeter vs greedy mode. The SLICT mechanism is used in different application scenarios like sparse deployment and dense deployment in large rural areas and urban buildings, respectively.

CCN-WSN [60] for wireless sensor networks is lightweight CCN protocol to deliver the packets. CCN-WSN is a true alternative to IP implementation in sensor networks. Key concepts in CCNx protocols are combined in this approach, while computational and memory constraints are revised for enhanced working. CCN-WSN is a flexible naming strategy that covers the content names' functionality of adding some amount of data in INTEREST packets. Small data transmitted in WSNs are the motivation behind this flexible CCN-WSN.

Geographic INTEREST forwarding (GIF) [68] is another efficient forwarding scheme. In the proposed novel scheme support for Push based traffic is provided for NDN-IOT environment. In GIF two type of objectives are there: Without any INTEREST request sensor node will send the DATA towards the sink node. And producer node's existence announcement to the sink nodes. Greedy approach is used by the GIF for the message route that is aware of energy. First, a 'Hello packet' send by all the nodes in the network. Hello packet consists of the residual energy of the node, nodes' identity and the node's position. This phase is called the neighbor discovery phase and this procedure is done once while the start of the network. Data types and the coordinates of the nodes send by the nodes towards the sink node using the Push mechanism. Finally, the neigbour and producer tables are updated in each node. Whenever a sink node requests the data from the producer node. It will discover the neighbor closest to the producer having enough energy power and having path to forward the data towards the producer node. Data naming, discovery of the neighbor, discovery of producer and exchange of the data are the basic modules of the scheme. GIF reduces the broadcast storm by reducing the number of INTERESTs, reduce the packet drop and improve energy efficiency.

Forwarding strategies in NDN based WSNs are summarized comprehensively in Table IV.

### A. *Comparative Analysis*

In wireless sensor networks in NDN, research work is not that much as compare to NDN based MANETs and VANETs. CCN-WSN [60] and basic NDN approach are some early work in this domain that were not that efficient in sensor environments. Directed diffusion [55] was the earliest work in this domain. DD-NDN [54] enhance the methodology of Directed Diffusion that increase the availability of path information and reduce the collision. Plain vanilla supports the push-based traffic. The best work in this domain till date is DMIF [57] in which two combined mechanisms directive and flooding modes are proposed. DMIF reduces the broadcast storm and energy consumption. The latest work in this domain is GIF that use the provider aware forwarding mechanism and sink nodes to balance the flow of forwarding packets. GIF [68] reduces the number of INTEREST and the energy consumption. GIF compared to DMIF, DD-NDN is performing very well because of its mechanism that reduces the total number of INTERESTS and energy consumption.

## VII. Forwarding in NDN Based Wireless Mesh Networks

In this section, we discuss the forwarding techniques in NDN based wireless mesh network (WMN). WMNs are normally consist of Mesh clients, routers, and mesh gateways, as shown in the architecture of WMNs in Fig. 13. If we consider cell phones, laptops, and other devices that work wirelessly, then these all are mesh clients in WMNs. Mesh routers used to forward the traffic through gateways. Mesh networks may consist of mobile or fixed devices [6]. The solutions in mesh networks are diverse according to the need of the communication. In difficult circumstances such as battlefield surveillance,

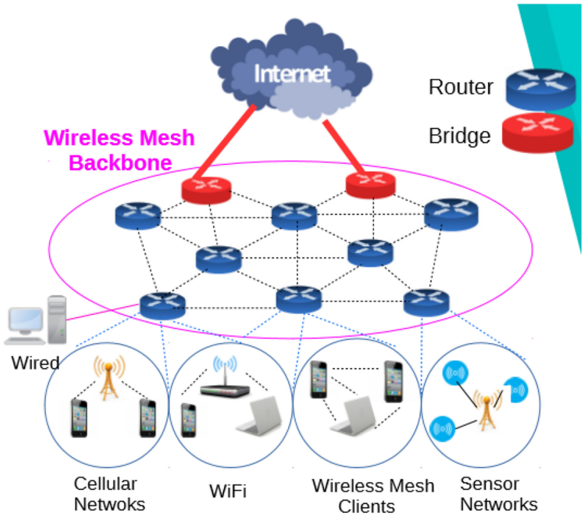


Fig. 13. Wireless Mesh Network.

oil rigs, high-speed mobile video applications, emergency situations, and in tunnels mesh network solutions are used to communicate effectively. NDN is a promising architecture, in which plenty of work and research has been going on, but there are still problems of limiting the hop count in communication of multimedia chunks. INTEREST for each chunk in NDN delays the retrieving or publishing of video content in efficient and fast manners. In this section, we will discuss routing and forwarding mechanisms in WMN that are specific to futuristic Internet paradigm NDN.

### A. Forwarding Strategies

A forwarding strategy for real-time video over CCN is presented and termed adaptive retransmission scheme [61]. In this forwarding mechanism, packet loss nature of wireless mode is considered that effects performance of video streaming dramatically. Proposed mechanism is a novel and efficient method that uses effective retransmission of INTEREST packets to reduce the packet loss during video streaming. The scheme incorporates retransmission algorithms and is based on client-side deployment. An explicit congestion notification field ECN is embedded by the retransmission control algorithm to signal the consumer about the network congestion. The ECN field also helps in making a difference of channel error and congestion in network. Retransmission window size is adjusted adaptively to deal with the packet loss against the retransmitted INTEREST by the consumer.

A peer-to-peer live adaptive application [62] is proposed over cellular networks related to the ICN architecture based on the mechanism related to ICN for live streaming of videos. For adaptive and dynamic streaming, CCN architecture is used along with MPEG DASH. This proposed application makes full use of both proximity networks Wi-fi direct and cellular 3G network to provide dynamic, live, and adaptive streaming of video. A bunch of neighboring consumers watching the same video content, connected in a full mesh network with one hop, exchange data with each other, and fetch content at various adaptive rates collaboratively. Through the connection of cellular networks and consumers with producers or the video server that provides the content related to the video, and when both are connected through Wi-fi, MPEG DASH-based applications are used by consumers to fetch the video chunks collaboratively and share in P2P fashion with others.

COCONET (COntent-centric COmmunication in multihop NETworks) [63] is an augmented architecture that extends the CHANET to another forwarding strategy that covers the MANET area. COCONET supports the content delivery and discovery along with caching in the access segment of wireless mesh networks. Content retrieval in COCONET relies on two phases:

1. Content discovery
2. Content delivery

A consumer first broadcasts the INTEREST packet and identifies the provider(s) that is reachable based on the DATA objects that are received.

COCONET implements a packet duplication avoidance technique to improve scalability and energy efficiency, based on information that is local and no explicit exchange of signals with neighboring nodes. Counter-based schemes are used to mitigate the broadcast storm problem. Counter-based schemes are also the part of forwarding decision. An INTEREST is broadcast by the consumer for the first chunk of content. Any node first searches and looks at its SeqNum and HopNum fields for packet validity check on INTEREST reception. When the packet validity succeeds, then the node checks its content store for cached content and in case of content presence, the node behaves like a provider. Moreover, duplicate INTEREST requests can also be handled. The content delivery phase begins with the sending of the first DATA object from the Provider. The Provider sends as many DATA objects as INTEREST packets. All intermediate nodes will take the COCONET mechanism into account and check its PRT. In case the PRT check fails, the node will discard the packet, otherwise the node considers the distance related field and decreases the value of distance by one with each new node entry and compares it with the consumers distance. Compared to legacy approaches, the main reasons behind the better and robust performance of the COCONET are (i) COCONET makes full use of broadcast medium, (ii) the number of hops between stored content and consumers are reduced by in-network caching, (iii) power consumption and signaling overhead is successfully reduced with content-centric communication that encourages packet duplication avoidance and mitigation of broadcast storm.

To cope with the broadcast storm problem, three mechanisms are proposed in CCN-based wireless mesh networks, PIF, ReCIF, and ReCIF + PIF [64]. In Probabilistic INTEREST Forwarding (PIF) [64], a node forwards INTEREST packets with probability p, with a node having degree centrality g greater and equal to G (threshold). In case of lower degree centrality g and equal G, the standard CCN forwarding scheme is used to forward INTEREST packets. The aim of this mechanism with PIT is to reduce the packet transmission with a higher degree

TABLE V
FORWARDING STRATEGIES IN NDN BASED WMNS

| Forwarding Strategy | Type | Year | description | Benefit | Related Work |
|---|---|---|---|---|---|
| Adaptive retransmission scheme for video streaming over CCN | Adaptive | 2013 | In this forwarding mechanism packet loss nature of wireless mode is considered that effects performance of video streaming dramatically | Deal with packet loss and congestion | [61] |
| P2P live adaptive video streaming for ICN cellular networks | Adaptive | 2016 | make full use of both proximity network Wi-fi direct and cellular 3G network to provide dynamic, live and adaptive streaming of video. | Consumer fetch the video chunks collaboratively and sharing in P2P fashion with others | [62] |
| COCONET | Hop aware | 2015 | Content retrieval in COCONET relies on twophases.<br>1. Content discovery<br>2. Content delivery | avoidance and mitigation of broadcast storm, Power consumption and signaling overhead is successfully reduced | [63] |
| PIF | Probabilistic | 2016 | Probability based forwarding with centrality threshold | Reduce broadcast storm problem | [64] |
| ReCIF | | | Aim of ReCIF is to,lessen the forwarding of the Interests that are in already storm condition. | Reduce broadcast storm | [64] |
| ReCIF+PIF | | 2016 | Combine both PIF and ReCIF | | [64] |
| AMVS-NDN | Adaptive | 2013 | a mobile station (MS) seeks to use either 3G/4G or Wi-Fi links opportunistically, and (2) MSs can share content directly by exploiting local Wi-Fi connectivity | Less cellular traffic and higher quality of video sharing are benefits of AMVS-NDN. | [65] |
| DAF | Direction aware | 2018 | Packet is transmitted by taking the direction and the speed of the high mobile node. | Enhance and improve the bandwidth and reliability scenarios of high mobility | [69] |

of centrality, which means a greater number of neighbors. More nodes will ask for the medium after forwarding the packet from the node that has a higher degree of centrality and thus the packet will cause the broadcast storm problem.

The Retransmission-Counter-based INTEREST Forwarding (ReCIF) [64] mechanism introduces the forwarding counter in the forwarding header field, with initial value zero and value increasing with each forwarding step. Nodes with a degree of centrality g greater and equal to G, forward an INTEREST packet in case of ci less than C, (ci = forwarding counter, and C = retransmission threshold). Default CCN forwarding mechanisms are used to forward the INTEREST if g is less than G. The forwarding counter will increase faster in a broadcast storm situation. The aim of ReCIF is to lessen the forwarding of the INTERESTs that are already in storm condition.

ReCIF + PIF [64] Mechanism combines the features of PIF and ReCIF. This mechanism also includes the forwarding counter, and both ReCIF and PIF are considered during this mechanism forwarding.

Adaptive mobile video streaming and sharing in the NDN architecture (AMVS-NDN) [65] is a purposed solution for video streaming problems, considers the multiple wireless interfaces—3G and Wi-Fi—of mobile networks. AMVS-NDN functionalities are (1) a mobile station (MS) line opportunistically seeks to use either Wi-Fi or 3G/4G links, and (2) by exploiting local Wi-Fi connectivity, MSs can share content directly. Higher quality of video sharing and less cellular traffic are benefits of AMVS-NDN.

Direction aware Forwarding (DAF) [69] proposed in wireless mesh networking to enhance and improve the bandwidth and reliability scenarios of high mobility. Packet is transmitted by taking the direction and the speed of the high mobile node. High speed trains are the example scenario for this proposed scheme. Proposed scheme significantly reduces the handoff delay, network load and redundancy of the data. Packet loss rate is also improved significantly. An additional DF bit is added in the packet for the INTEREST forwarding that is the INTEREST forwarding direction. Right direction of INTEREST is defined by the true DF flag. Multiple access nodes are there to forward the INTEREST in high speed scenarios.

Forwarding strategies in NDN-based WMNs are summarized comprehensively in Table V.

### B. Comparative Analysis

In NDN based WMNs limited work has been proposed. To end of the date, ReCIF and PIF are the best forwarding strategies in WMNs. ReCIF limit the number of interest and combine with PIF, both produce good results. COCONET [63] also avoid broadcast storm and power consumption. Compare to later the earlier strategies gives the best of the results. REeCIF combined with PIF [64] reduce the number of interest using its probabilistic forwarding method that reduce the broadcast storm as well. Direction aware Forwarding (DAF) [69] proposed in wireless mesh networking to enhance and improve the bandwidth and reliability scenarios of high mobility.

TABLE VI
SUITABILITY AND BEST PERFORMING FORWARDING STRATEGIES IN WIRELESS NETWORKS

| Forwarding Strategy | | Suitability for Wireless Network | | | | Best Performing Strategies |
|---|---|---|---|---|---|---|
| | | *MANET* | *VANET* | *WSN* | *WMN* | |
| ***Flooding Based Forwarding*** | | Yes | Yes | Yes | Yes | Blind Forwarding[16], [52] |
| ***Adaptive Forwarding*** | | Yes | Yes | Yes | Yes | SAF[17], AFIRM[72] |
| ***Aware Forwarding*** ***Aware Forwarding*** | Distance Aware | Yes Yes | Yes Yes | Yes Yes | Yes Yes | NVP[49] |
| | Neighbor Aware | | | | | NAIF[25], RUFS[48] |
| | Context Aware | | | | | CARP[39] |
| | Provider Aware | | | | | E-CHANET[21] |
| | Next hop Aware | | | | | GACF[18] |
| | Location Aware | | | | | LOMCF[30], GIF[68], NAVIGO[43] |
| | Direction Aware | | | | | DAF[69], VNDN[51] |
| | Path Aware | | | | | dd-NDN[54] |
| | Link Stability Aware | | | | | LSIF[79] |
| ***Congestion Control Forwarding*** | | Yes | No | Yes | Yes | SIRC[34] |
| ***Energy Efficient Forwarding*** | | Yes | No | Yes | Yes | OEFS[32], DEMIF[57] |

## VIII. KEY ISSUES AND OPEN CHALLENGES NDN FORWARDING

In this section of the paper, we present the issues regarding forwarding in all discussed networks based on NDN. Research challenges and future directions are also discussed comprehensively related to the forwarding and routing. We identify the following key problems within the design of a scalable NDN forwarding plane [9]:

1. Exact string matching with fast updates
2. Longest prefix matching(LPM) for variable-length and unbounded names
3. Large-scale flow maintenance

NDN forwarding plane encourages speedy and fast packet Name lookup, efficient and intelligent forwarding techniques, and efficient cache replacement strategies. NDN forwarding is more complicated and challenging if we compare it with IP. Broadcast storm and multihop forwarding are also the problems in NDN forwarding. Large scale deployment of NDN architecture needs enormous efforts in terms of scalable forwarding. In our survey, we discuss important design principles and the potential opportunities to solve the issues discussed above and those for optimization. Some effective solutions for scalable forwarding are discussed in [9].

- Aim for Constant-Time Operations
- URL-format for Optimization
- Simple DATA Structures for Fast Updates
- Efficient and robust Packet Encoding and decoding
- Various Content Store Policies

NDN is a promising future Internet architecture paradigm. NDN secures content rather than securing the data container, and supports efficient distribution of content. There still exist challenges to the potentialities of CCN/NDN paradigms applied to MANETs, VANETs, WSNs, and Mesh networks. Some forwarding issues are resolved by NDN forwarding, such as address space exhaustion, mobility, address management, and NAT traversal. Forwarding strategies discover the multi-path ability of NDN and select best outbound interface(s) to forward INTEREST packets. This supports congestion control, load-balancing across paths, link failure, and spots attacks. The number of proposals handling CCN routing and forwarding challenges in wireless environments are witness to the interest of the research community in these topics. There are still open challenges to designing efficient and effective forwarding strategies for various networks and contexts. Independently moving devices related to MANETs, in any direction and changing its links frequently to other devices resulting in extreme packet losses in fast-changing topology. There are challenges to meet these requirements. INTEREST message flooding is a promising research issue in MANETs. Flooding can cause problems like congestion, redundancy and packet loss. There are issues of content delivery and packet forwarding in mesh networks with unstable and narrow wireless links. NDN involves a pull-based content delivery method that accommodates efficient packet forwarding and content delivery very well. Mesh networks involve mobile or fixed devices. In situations/areas such as tunnels, battlefield surveillance, oil rigs, applications of high-speed mobile videos and local call systems, a large amount of state, content prefix, and distribution of routing instructions are also challenges. Load balancing and INTEREST time out scalability is also a key challenge. Load balancing is very important in forwarding mechanisms related to WSNs, because we can attain efficient results to prevent the node's energy through efficient load balancing. Simple and secure namespace mapping is a possible solution to the scalability problem. Thus, Namespace design is a serious area of research. Efficient strategies to fetch data within the intended scope are a new research area [2]. Efficient lookup and operation on the PIT is a research question. In highly dynamic networks, handling the NDN mobility is an open research issue. Fault detection, recovery, and error control are responsibilities of the NDN forwarding plane. With the reduced role of routing in NDN forwarding, extensive study is needed in areas of forwarding and routing, which do not still exist in the current Internet.

## IX. CONCLUSION

In this paper we discussed the architecture of NDN, forwarding strategies, enhancements and modifications in forwarding strategies and role of NDN in wireless ad hoc networks. The focus has been on the forwarding strategies and open challenges in this paper. To understand NDN better, a brief comparison of NDN and IP have been presented. Forwarding strategies have been nicely categorized for a broader view and understanding. MANET, VANET, WSN and WMN are the networks on which we conducted this survey. We discussed application scenarios and use cases for forwarding strategies in above disused networks also. Issues regarding forwarding in NDN, open challenges and future research directions have also been discussed.

All in all, the survey conducted in this paper shows that there is enough space to design more intelligent and enhanced forwarding strategies in wireless ad hoc networks. Moreover, this survey paper encourages the research community of NDN for more dedicated efforts to this topic of research.

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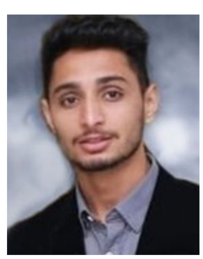

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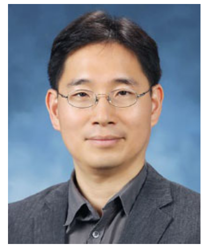

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