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Interest Broadcast Suppression Scheme for Named Data Wireless Sensor Networks

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ABSTRACT Named data networking (NDN) is one of the future networking architectures that communicates content using names, instead of the node addresses. It uses a very simple pull-based communication mechanism to retrieve content by sending an Interest message, and the node that has the required content or producer node replies with the data message. In wireless networks, the interest is flooded in the network to find the data provider node. The directional diffusion method is used to pull further content from the provider node. Due to broadcast nature and without node addresses, interest flooding causes network congestion and wastes network resources, especially bandwidth and battery power. These resources have prime importance in the case of wireless sensor networks (WSNs) because all WSN nodes operate on battery and have limited bandwidth. In this paper, we propose an interest broadcast suppression scheme that considers interest holding time using the distance between forwarder and receiver of the interest, energy, angle, and distance from the beeline between consumer and the spatial region, to avoid broadcasting of unnecessary copies of Interest. The simulation results show that the proposed scheme mitigates the interest broadcast and conserves battery power of the wireless nodes compared with the state-of-the-art scheme in the domain.

INDEX TERMS NDN, WSN, interest, holding time, broadcast storm.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are a reality of the current era because of their potential to be part of many application domains [1]. These domains range from healthcare, Internet of Things (IoT), to smart cities. WSN consists of battery operated nodes with wireless communication and sensing capabilities. These nodes are deployed to monitor the physical parameters, i.e., vital signs of the human body, surveillance of the harsh and remote area, monitoring the architectures, etc. In addition to sensing, the WSN nodes forward those updated parameters to the surveillance or monitoring station through the base station(s) (BSs) in a multi-hop manner. Due to the scarce battery and bandwidth resources of the network, researchers have proposed many solutions to conserve these resources [2]. Data is collected from sensor nodes either in response to the request initiated by the BS (pull-based) or forward data to the BS without any request (Push-based). Commonly, the WSN nodes are assigned unique labels or IDs to identify the nodes and use those IDs to cooperatively communicate with other nodes in the network or nodes outside the network [3], e.g., 6LoWPAN. However, the core objective of WSN is to monitor by continuously collecting the sensed data.

Recently, Named Data Networking (NDN) [4], one of the future Internet architectures [5], has gained a lot of attention from the research community. NDN decouples data from its location plus the node's identity for efficient collection, dissemination, and name based services for data by exploiting the in-network caching. Instead of securing the connection, NDN intrinsically secures the data itself.

NDN is a variant implementation of its predecessor architecture, called Content-Centric Networking (CCN) [6]. NDN considers data or content at the center of communication

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instead of the location or IP of the content or the node that provides the content. The terms content and data are used interchangeably in the context of this paper. In the context of NDN, each content is accessed and routed in the network using its *Name*. A simple pull-based communication process is adapted by NDN, where the content requesting node (called consumer) generates the content request message, named Interest message. Interest message contains Name of the content and a large random number (called *NONCE*) that uniquely identifies the Interest message. The node with matching named content, designated as Provider, replies with the Data message to the consumer once it receives the Interest message.

NDN maintains different data structures at each node to efficiently forward Interest and Data messages. These data structures are Pending Interest Table (PIT), Forwarding Information Base (FIB), and Content Store (CS). PIT structure is implemented to keep the state of the incoming Interest message's Name, NONCE, and Interface from which the Interest was received (called inFace). This *inFace* is also used to forward Data message that is received in response to the Interest with the matching Name entry in the PIT. On the contrary, the FIB consists of Name prefixes and the outgoing interfaces (outFace) where the Interest should be forwarded once the matching Name is found in the FIB. The complete or partial content received in the Data messages is cached in the CS to satisfy future Interest requesting similar content.

The core objective of NDN is to discover content from the network without prior knowledge of the provider or content location, which suits the distributed content dissemination nature of WSN. Hence, different solutions have been proposed that investigated the feasibility and applicability of NDN in WSN [7]–[14].

In WSN, to find the provider(s), all the schemes first flood the Interest to locate the provider nodes in the specified network area (called Blind Forwarding). The term producer and provider are interchangeable in the context of this paper. When all the nodes that participated in the Interest forwarding process, receive the first copy of the Data message, they store path information related to the producer of that Data message including; energy, distance, hops, etc. in their FIBs. Using this FIB information, the later Interest messages are forwarded to that provider and is called aware forwarding or directive forwarding. However, the broadcast storm in the initial stage consumes an ample amount of network energy and other resources. Hence, most of the previous schemes employ different methods to avoid the broadcast storm, e.g., Interest-Data holding timers, scope control, etc. In this paper, we use directive forwarding of the Interest messages in the first stage based on the spatial information that is included in the content *Name*. It is evident that the WSN applications require recent information about the specific network area, we call it Interest Region (*IR*). This is only possible if the sensor(s) are deployed in the *IR*. Hence, our proposed scheme uses directive dissemination of Interest messages to find the provider(s) using angular, energy, and distance information between consumer and the *IR*.

The contributions of this paper are four folded:

- The proposed Interest-Data forwarding mechanism does not use any node identity and is compatible with the vanilla NDN architecture.
- It overcomes the Interest broadcast storm by using the spatial component of content *Name* plus node's energy and location information, to avoid the excessive control overhead in the battery constrained WSN.
- Our proposed scheme does not use any additional information in the Interest message other than the location of the Interest forwarding node, which is only a couple of bytes.
- The proposed scheme does not maintain any additional information in FIB to reduce the broadcast storm.

Rest of the paper is organized as follows. In Section II, the introduction of NDN architecture, working principle, and recent work that employed NDN in WSNs have been discussed. The proposed Interest dissemination scheme is briefly elaborated in Section III. The simulation environment and results are analyzed in Section IV. Finally, Section V concludes the paper.

II. BACKGROUND AND RELATED WORK

A. WORKING PRINCIPLE OF NDN

As stated earlier, in vanilla CCN and NDN, every node primarily uses three data structures PIT, FIB, and CS to forward Interest and Data messages.

- *PIT {Name, NONCE(s), inFace(s)}*: state of the Interests is stored in PIT. Upon reception of an Interest {*Name*,*NONCE*} from the *inFace*, the *Name* from the Interest is searched in the PIT. If the similar *Name* is present in the PIT with different *NONCE* or *inFace*, the PIT is updated with the *NONCE* or *inFace*, and the Interest is discarded. Conversely, the {*Name*, *NONCE*, *inFace*} are added in the PIT.
- *FIB {Name, outFace(s) M}*: it is used to forward Interest towards the potential provider(s) in the upstream direction. Based on the *Name* search result from the FIB, the Interest is forwarded to the corresponding *outFace*. Otherwise, the Interest is flooded to all the *outFaces* or discarded, which depends upon the forwarding strategy. The *outFace*'s routing metric *M* indicates its preference to forward the Interest through that *outFace*. If the matched FIB entry has multiple *outFaces*, then the *outFace* with lowest *M* is preferred. FIB is populated with new entries (*outFaces* and *Name* prefixes) using static routes or as per the routing policies.
- **CS**: is Data message cache. Caching of Data messages depends upon the caching policy.

In principle, NDN does not forward an Interest to the same *Face* from which it is received; *inFace* $\neq$ *outFace*. However, in resource-constrained WSN, almost all the nodes are equipped with a single interface and Interests-Data messages must be forwarded through that interface. Hence, controlling the broadcast storm in a single wireless interface is a challenging task. In this paper, all nodes have single IEEE 802.15.4 wireless interface and Interest-Data messages use that single interface. In literature, most of the previously proposed schemes for NDN-based WSN consider the single *Face* scenario and their Interest broadcast storm mitigation methods are briefly discussed in Section III.

B. RELATED WORK

In [7], the authors proposed the naming scheme for WSN that comprises different attributes including the type of sensing task (humidity, temperature, etc.), location (room1, park A, etc.), task time, and a random value, e.g., "/humidity/corridorwest/time1/3214". Initially, a node will broadcast Interest message (blind forwarding) and upon reception of the first data message all the intermediate nodes will keep the network state information because the WSN topology does not change frequently. During blind forwarding, each node receives Interest and forwards it on the same interface, and the Data messages are forwarded based on the PIT information. To minimize the broadcast storm, authors introduced the concept of defer window that includes timers for Interest and Data messages. Transmission of these messages is deferred until the timers are ON and these messages are discarded if any other copy of the message is received before expiration of the respective timers. However, PIT entry is maintained at each node irrespective of the Interest timer. After the initial blind forwarding of Interest-Data messages, the state information stored at intermediate nodes for future Interest-Data communication to those providers. Based on the state information available in the network, the subsequent Interest-Data messages are forwarded using the directed diffusion technique.

An Interest flooding control scheme, called Adaptive Interest Forwarding (AIF), has been proposed in [8]. AIF employs the defer window timer to suppress Interest flooding in a wireless network where all nodes are equipped with IEEE 802.11g interface. Defer window computation involves node's energy level, IEEE 802.11g DIFS slot duration in μs, and a random component. Authors in [9] also implemented the vanilla Interest flooding (VIF) and Reactive Optimistic Name-based Routing (RONR) as in [7]. Initially, an Interest is simply flooded in the network and the FIB is populated with the reverse path information taken by the first Data message received by the nodes.

The advantages of applying NDN in IoT such as mobility support, security, and efficient data aggregation, have been analyzed in [10]. The authors presented the IoT specific architecture inline with the IoT challenges. A simplified version of CCN has been proposed in [11] to achieve time synchronization in the network. Node's clock information is shared using CCN messaging. A modified structure of the Interest and Data messages has been proposed that matched the computation and memory requirements of WSN without compromising the functionality of the CCN. The authors proposed a simple hierarchical naming scheme with some coding rules to match the desired data within the network.

A single hop multi-producer data retrieval framework for IoT has been proposed in [12]. Interest message limits the number of producers or contents (N) in the Interest message and based on that information only the intended producers or copies of the Data messages from the single hop are restricted. They set the scope field of Interest message to limit the broadcast range of the message. To avoid the collision, authors also applied the Interest-Data defer timers. Authors in [13] proposed the wireless recharging framework for the NDN enabled hierarchical topology WSN. The network area is divided into multiple sections where each section is assigned a head node. Battery level information of the network is collected through initiating the energy Interest message. Every node replies to this energy Interest with the node ID and energy level Data message. Sector-wise energy is collected by the area head and then forwarded to the mobile node for battery recharging. This energy information is also used to select the area heads. Hierarchical naming scheme appropriate because it matches the network topology and is adapted in this work.

Recently, authors in [14] proposed the dual mode Interest forwarding scheme for WSN: flooding mode and directive mode. As in [7], flooding mode discovers the providers and then the directive mode is used for future Interest forwarding to those providers. Authors used scope control, broadcast storm avoidance, and packet suppression algorithm to alleviate the Interest-Data load in the network. In the scope control method, authors used the legacy TTL (Time To Live) in Interest to control its dissemination range in the network. Additionally, they introduced holding timers for Interest and Data message that employ the energy consumption and distance information in Interest's timer computation. Interest's holding time computation also involves the weighting factors for energy and distance to prioritize any of the factors. Path information from the consumer to providers along with their energy information is stored in FIB for future Interest forwarding to those providers [7]. Interest-Data flooding suppression algorithm overcomes the flooding of those messages by discarding the transmission of that packet if a node receives more than one copy of that message until their respective timers expire. It shows that the node is a potential forwarder because its timer expired before all of its neighbors. Once the potential providers are located, then directive mode uses the number of hops and energy information from FIB to forward the Interest.

From the above discussion, it is observed that locating providers in WSN using the Interest flooding method is more energy demanding. Therefore, in this paper, we tackle this issue by proposing an energy efficient Interest broadcast suppression scheme to discover providers (or first Data message is received from the providers). Performance of our proposed scheme is compared with the state of the art Interest broadcast storm mitigation scheme in the literature, that is the one proposed in [14]. Throughout this paper, that scheme is called the conventional scheme. Our proposed scheme is briefly discussed in the next section.

III. PROPOSED INTEREST SUPPRESSION SCHEME

All communications in NDN based networks use the content name to perform Interest-Data communication. Therefore, the naming is at the center of NDN based networks. It must clearly describe the temporal, spatial, and type information of the sensed parameter for WSN. Our proposed scheme also uses the hierarchical content naming scheme consisting of different attributes separated by "/", as in [7]. Following assumptions are considered by our proposed scheme. Each node is equipped with GPS and is aware of its own location information. Similarly, every node has knowledge about its initial battery and current status of the remaining battery power. All nodes are homogeneous in terms of transmission range. A consumer sends Interest with the following naming convention:

- *Spatial Attribute:* indicates the *IR* that consumer is interested to receive the sensed parameter. This can be the number or name of a building, block, room, building section, floor, boundaries of a geographic region, etc.
- *Temporal Attribute:* represents the time period during which the consumer is seeking the sensed data. It can be the time interval (between t_1 and t_2) or time instance t_i after which the recent data is available at the sensor node. A time instance is represented in a UNIX timestamp format in this attribute.
- *Sensed Parameter (SP) Type:* This represents the type of sensed data e.g., humidity, temperature, mositure, air pressure, etc.

Following is the example of the *Name* used in the Interest.
/Sptial attribute/temporal attribute/SP:Type

(a) `/`(x_1,y_1)`:`(x_2,y_2)`/Timestamp1:Timestamp2/Temperature`
(b) `/Building09/Timestamp1/Humidity`

In first example, the consumer requires `Temperature` of a rectangular region bounded between two opposite corners (x_1, y_1) and (x_2, y_2) and duration between `Timestamp1` and `Timestamp2`. In next example, the recent `Humidity` information of `Building09` after time instance `Timestamp1` is interested by the consumer. In both the naming examples, spatial or *IR* information describes the boundaries of an area or logical name of a physical location and it is used by our proposed scheme to forward Interests.

A. PROPOSED INTEREST-DATA FORWARDING

Let, node i receives an Interest message I [*NONCE*,*Name*, *IR*,(x_F, y_F)] from node F that either generated or forwarded the Interest. In I, the *NONCE* uniquely identifies I, the *IR* consists the coordinates of the Interest Region, and (x_F, y_F) represents the node F's location information. Our proposed Interest suppression scheme selects potential Interest forwarder that has large residual energy (E_r), at farther distance from the forwarder ($d_{(i,F)}$) and closer to the center line between forwarder and the *IR* (θ_i), as shown in Fig. 1. Note that the forwarder in the scenario shown in Fig. 1 is the BS. It shows that BS generates I and all the nodes in transmission range of BS (T_r^{BS}) receive I. In vanilla NDN architecture, all nodes that receive new I, create a PIT entry and forward I. However, in our proposed scheme, only the potential forwarder can only forward the I. To achieve this goal, a new holding time for Interest containing specific content *Name* (HT_I^{Name}) is used by our proposed scheme. The HT_I^{Name} for a potential node is less than the other nodes in the transmission range of the Interest forwarder F, which is BS in this scenario, to prioritize Interest forwarding through those potential nodes only. As per the network scenario in Fig. 1, the nodes i and j are the potential forwarders because they are at farthest distance to BS and also have less distance to the line of sight between BS and center of IR, C.

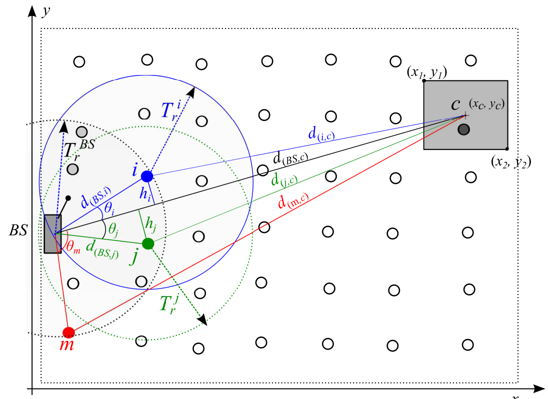


FIGURE 1. NDN-based WSN scenario for Interest broadcast suppression.

To prioritize forwarding of I through these potential nodes, HT_I^{Name} is computed as follows:

$$HT_I^{Name} = t_d + \frac{1}{3}\left(atan\left(\frac{E_i}{E_{Initial}^i}\right) + \left(\frac{T_r^F - d_{(i,F)}}{T_r}\right) + \theta_i\left(\frac{h_i}{T_r}\right)\right) \quad (1)$$

where t_d is the basic Interest holding time. E_i are $E_{Initial}^i$ are the residual and initially assigned energy levels of node i. T_r^F is the transmission range of the forwarder node F (that is BS in this scenario), which is assumed to be equal for nodes in the network. From the above expression it is obvious that the node HT_I^{Name} is inversely proportional to E_i, and $d_{(i,F)}$ and directly proportional to θ_i and h_i. The computation of those parameters is discussed below. The distance between node i and forwarder F, $d_{(i,F)}$ is simply the Euclidean distance between them.

$$d_{(i,F)} = \sqrt{(x_i - x_F)^2 + (y_i - y_F)^2} \quad (2)$$

The distance of node i from the line of sight between F and C (center of IR region), h_i, is calculated as:

$$h_i = \frac{1}{2}\frac{\sqrt{4d^2_{(i,C)}d^2_{(i,F)} - \left(d^2_{(i,C)} + d^2_{(i,F)} - d^2_{(F,C)}\right)}}{d_{(F,C)}} \quad (3)$$

Similarly, θ_i (in radians) can be calculated by using the simple trigonometric relations of a triangle F, i, and C, as:

$$\theta_i = cos^{-1}\left(\frac{d^2_{(i,F)} + d^2_{(F,C)} - d^2_{(i,C)}}{2d_{(i,F)}d_{(F,C)}}\right) \quad (4)$$

The holding time for Data message (HT_D^{Name}) is same as in [7], [12], [14]:

$$HT_D^{Name} = rand\,[0.0, t_d] \quad (5)$$

HT_I^{Name} and HT_D^{Name} are the time durations that are used to defer the forwarding process of Interest and Data messages. Smaller the duration, the larger the chance for the node to forward the message. In addition to HT_I^{Name} and HT_D^{Name}, there are different counters as well as structures to defer the forwarding process of those messages. Detailed forwarding process of Interest and Data messages is briefly discussed below.

1) INTEREST MESSAGE FORWARDING

As stated earlier, node i receives an Interest message I [$NONCE$,$Name$, IR,(x_F, y_F)] from node F that either generated or forwarded the Interest. In addition to the parameters received in I, every node also utilizes Recently Satisfied *NONCE* list (RS_{NONCE}) to avoid the routing loop and unnecessary longest *Name* prefix search in the PIT. Proposed Interest forwarding algorithm also uses the modified holding time for Interest with *Name*, HT_I^{Name}, and similar HT_D^{Name} as in [14].

When i receives an Interest I, it performs the following proposed steps to suppress the Interest broadcast storm. These steps are also summarized in Fig. 2. After receiving an Interest, node i searches *NONCE* in the RS_{NONCE} to ensure whether the Interest has been recently satisfied or not. NONCEs of the satisfied Interests are stored in the RS_{NONCE} for 4s that is long enough to receive the copy of same Interest or Data from the longest route in the network. If NONCE is found in the RS_{NONCE}, then the Interest as well as Data are discarded. However, in case, there is no entry for the NONCE in the RS_{NONCE}, i parses the information received in I within other structures maintained at node. First, it checks either node itself is in the IR or has the requested content cached in its CS. In any case, the node replies Interest with the Data message and adds the *NONCE* in the RS_{NONCE} list. Node i can be in IR if it satisfies the following condition.

$$(x_1 \leq x_i \leq x_2)\ and\ (y_1 \leq y_i \leq y_2)$$

where (x_1, x_2) and (y_1, y_2) are the boundaries of the IR region and (x_i, y_i) is the current location of the node i. Node i searches its PIT provided that i is neither in IR or it has

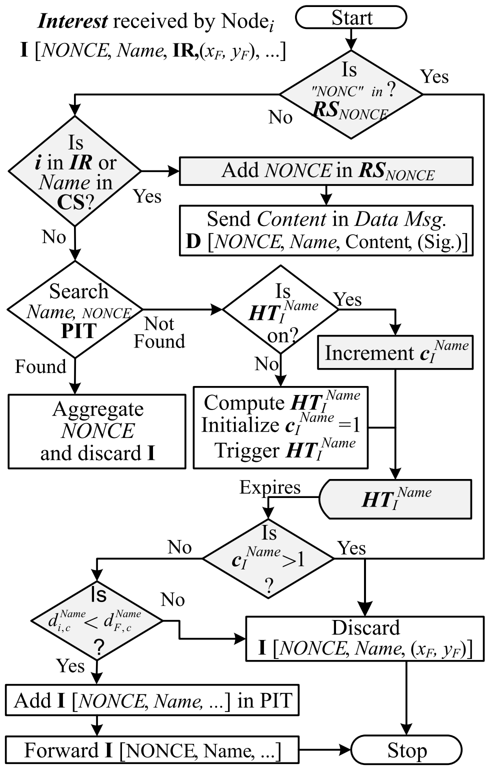


FIGURE 2. Proposed interest broadcast suppression algorithm.

the requested content in its CS. Presence of an entry for the same *Name* in the PIT signifies that I has already been forwarded and does not need to be forwarded again. Hence, the NONCE is aggregated in the PIT under the same *Name* and I is discarded. Then i checks that either HT_I^{Name} timer for the received *Name* is already on or off. If the Interest's timer is already running and not yet expired, then node just increments the Interest counter for that name, c_I^{Name}, and waits until that timer expires. In later case, it computes HT_I^{Name}, initializes $c_I^{Name} = 1$ and triggers the timer. Until HT_I^{Name} is running and node i receives multiple Is, it increments the c_I^{Name} upon reception of every copy of I.

When HT_I^{Name} expires, the node i checks whether it received only one copy or multiple copies of I. Reception of multiple copies before the expiration of HT_I^{Name} denote that there may be other nodes in the neighborhood that may be the next potential forwarder(s) for I. Hence, i defers the Interest forwarding without adding PIT entry. It ensures that this node does not take part in Interest-Data communication in future and conserve energy. If HT_I^{Name} at i expires and the node just receives only one copy of the Interest, then it compares the distance between node i and the center of IR, c, ($d_{i,c}^{Name}$) and forwarder and the center of IR ($d_{F,c}^{Name}$). This condition constraints all the nodes not to forward I but only the nodes that are between i and IR. Node i creates PIT entry first and then forwards the I if it satisfies the above condition.

It is worth noting that PIT entry is not created by a node until its HT_I^{Name} does not expire, it does receive only one copy of the I from its neighbors, and is located between F and IR. Additionally, HT_I^{Name} of the nodes that are at a farther distance from the forwarder, closer to the center line between the forwarder and the IR, and have more residual energy, expires earlier than the other nodes in the proximity. Subsequently, it suppresses the Interest broadcast storm and distributes the Interest forwarding load to the potential nodes in the neighborhood. In addition to that, our proposed scheme has less Interest satisfaction delay because it forwards the Interest in the direction of the IR. Consider the scenario in Fig.1 where all nodes have equal E_i. In this case, the node i is the potential forwarder and because i has large $d_{BS,i}$, small θ_i, and h_i. By using our proposed algorithm, all nodes in T_r^i and as well as node m suppress their Interest forwarding. The nodes in T_r^i will receive copy of the Interest from i in addition to the Interest they received from BS. Node m has larger distance to center of IR, $d_{m,c}$, than the distance between BS and c, $d_{m,c}$. Hence, node m will be forced by the last condition of our Interest flooding control algorithm (Is $d_{i,c} < d_{F,c}$) to suppress the Interest forwarding. Here, the forwarder F is BS and i is the interest receiving node m. However, in the conventional scheme, m and all the nodes that have a large distance to BS has equal chance to forward the Interest. In results, many copies of the Interest are disseminated by the conventional scheme in the Interest broadcast phase.

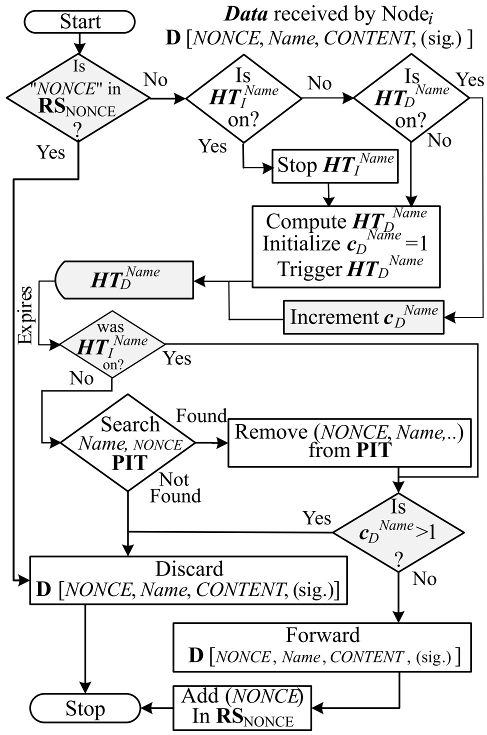


FIGURE 3. Data message forwarding algorithm.

2) DATA MESSAGE FORWARDING

Forwarding Data message D [*NONCE*,*Name*, *CONTENT*,(*sig.*)] also follows the similar set of rules as I, but uses different holding time for Data message HT_D^{Name}. D includes additional information i.e., required content that was requested in Interest (*CONTENT*) and signature *(sig.)* to verify the *CONTENT*. In vanilla NDN, D does not include the *NONCE* value, however, in our proposed scheme we forward the Interest's *NONCE* value in the D to overcome the Data message looping.

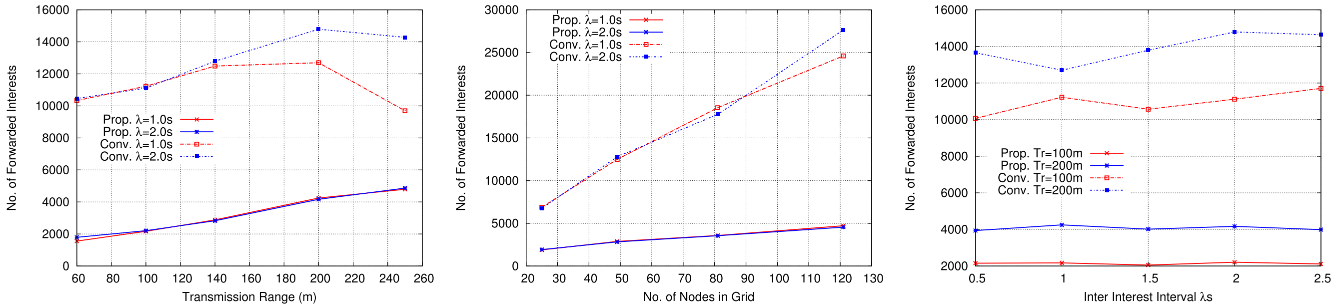
Similar to Interest message processing, when node i receives D, it first checks RS_{NONCE} to avoid the longest PIT search process. In case, there is no entry for the *NONCE* in the RS_{NONCE}, then HT_I^{Name} is checked. The ON state of HT_I^{Name} indicates that the Interest has recently been received and is in the forwarding process at node i. The HT_I^{Name} is stopped first because the Data message has been received for the Interest in process. There is no need to check HT_D^{Name} because these two timers cannot be on at the same time. Conversely, if HT_I^{Name} is off, the HT_D^{Name} is checked next to confirm that either it is the first copy of that data message or other copies has ready been in process at this node.

Contingent upon the status of HT_D^{Name}, the HT_D^{Name} is computed, the Data message counter c_D^{Name} is initialized, and HT_D^{Name} triggered in case the HT_D^{Name} is off. Otherwise, the c_D^{Name} is incremented. Once HT_D^{Name} expires, the Data message is forwarded if $c_D^{Name} = 1$ and *NONCE* is added in the RS_{NONCE}, otherwise, the message is dropped. Hence, the Data message is forwarded and RS_{NONCE} restricts Data as well as Interest looping. The above discussion related to the Data message forwarding is depicted in Fig.3.

In the following section, we briefly discuss the performance of our proposed scheme compared to the conventional scheme in [14].

IV. SIMULATION ANALYSIS

In this section, we briefly discuss and analyze the performance of our proposed and conventional scheme obtained through simulations in Network Simulator. For a complete analysis, we simulated the schemes for different network sizes ($N = (q \times q)$ WSN nodes plus one gateway, where $q = 5, 7, 9$, and 11), Transmission Ranges (T_r), and Inter Interest Interval (λ). Every wireless node is equipped with a single IEEE 802.15.4 interface and is static throughout the simulation time. All the sensors are deployed in a grid topology with the grid step GS of $50m$ within the network area $(q \times GS)^2$ m^2, where $A = 50m \times N$. The sink or gateway node is placed at the center of one side of the network area. Sink node works a consumer node that generates Interest with naming scheme mentioned above containing a randomly generated IR that less than the area of $GS \times GS$ to ensure one provider in that region. Inter Interest interval (λ) has been varied from $0.5s$, $1s$, to $2.5s$ to analyze the performance over different Interest load. An entry in the PIT for an unsatisfied Interest is purged after $4s$, which is default maximum lifetime of an entry in the vanilla NDN architecture. If no Data message for an Interest is received by the consumer, then consumer node retries by generating another Interest



(a) (b) (c)

FIGURE 4. Number of forwarded *interest* messages in the network for varying (a) T_r, (b) N, and (c) λ. (a) $\lambda = 1s, 2s$ and $N = 49$ nodes. (b) $\lambda = 1s, 2s$ and $T_r = 140m$. (c) $T_r = 100m, 200m$ and $N = 49$ nodes.

TABLE 1. Simulation parameters.

Simulation Parameter	Value
Interface	IEEE 802.15.4
Size of Data Message	100 bytes
Size of Interest Message	50 bytes
Transmission Range (T_r)	$60, 100, 140, 200$, and $250m$
Max. PIT Entry Lifetime	$4s$
Max. No. of Interest Retries	4
Inter Interest Interval (λ)	$0.5, 1.0, \ldots, 2.0s$
Network Size (N)	$N = 25, 49, 81$, and 121
Grid Step Size (GS)	$50m$
Network Area	$(N \times GS) \times (N \times GS)m^2$
Per Bit Energy Consumption	$0.5\mu J$
$E_{Initial}$	10 Joules
Simulation Duration	1000s

with the same *Name* but different *NONCE*. The maximum number of retries for an Interest is 4. The NDN forwarding daemon is implemented in Network Simulator (NS2). Rest of the parameters are summarized in Table 1.

Following parameters are the performance metrics that are measured through simulations and compared with the conventional scheme.

- *Forwarded Interest Messages:* is the total copies of Interest message propagated or forwarded by all nodes in the network.
- *Forwarded Data Messages:* is the total number of Data messages forwarded in the network.
- *Interest Satisfaction Ratio:* represents the ratio of the number of Data messages received by the consumer or BS in response to the number of Interest messages requested by the consumer.
- *Total Energy Consumption:* the sum of energy consumed by all nodes in the network.
- *Interest Satisfaction Delay:* it is the time duration between the instance when Interest generated by the consumer with *Name* and unique *NONCE* and it receives first copy of the Data message with the same *Name* and *NONCE*.

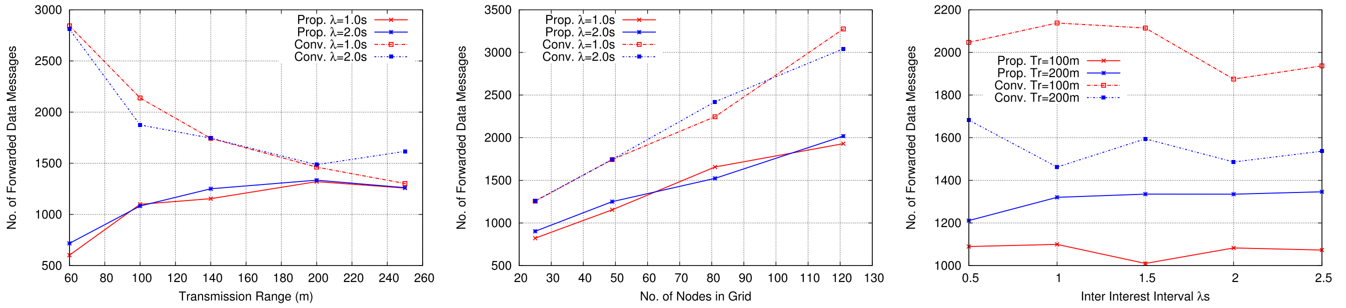
A. SIMULATION RESULTS

1) NUMBER OF FORWARDED INTEREST MESSAGES

Initially, we compare the number of Interests propagated in the network for varying T_r, network sizes, and λ, in Fig. 4a, 4b, and 4c, respectively. This includes the Interest generated by the consumer node and its copies forwarded by the intermediate nodes to find the producer(s). Conventional scheme simply floods the Interests and nodes at the farthest distance and large residual energy have a high probability to forward the Interest due to lower HT_I^{Name}. However, there may be the case that multiple nodes that are not in the transmission range of each other but in the transmission range forwarder, T_r^F. Correspondingly, multiple nodes at slightly different distances and with similar residual energy levels have almost equal HT_I^{Name}. These nodes forward interests with less time difference that cause Interest collision and high Interest drop. This scenario can occur when node density increases due to the increase in the transmission range and the network size, which is obvious from the Fig. 4a and Fig. 4b. On the other hand, it is observed that λ has not much impact on the number of Interests propagated in the network, refer Fig. 4a, because the first Data message is received for most of the Interests within *ms* duration, presented later in this section. For all T_r (Fig. 4a), N (Fig. 4b), and λ (Fig. 4c), approximately 73.65%, 80.0%, and 75.55% less number of Interests are propagated by the proposed scheme compared to [14], respectively.

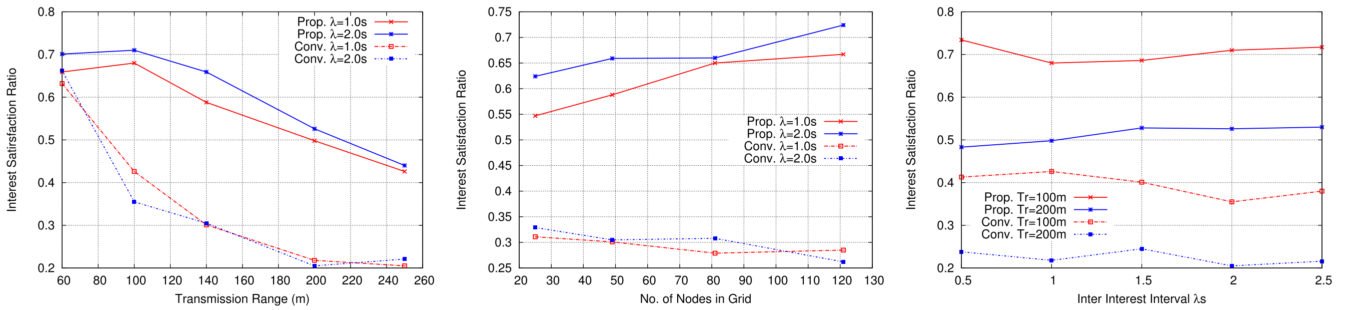
2) NUMBER OF FORWARDED DATA MESSAGES

The size of the Data message is larger than the Interest message. Therefore, the total copies of Data messages forwarded by a node have severe impact on the node's energy consumption and bandwidth utilization. In NDN, Data messages are only forwarded by the nodes that have PIT entry for the same *Name* that is in the Data message. In conventional scheme, all nodes that receive Interest message, create PIT entry whether they forward or defer the relaying of that Interest. Hence, there are many nodes with respective PIT entries and equal opportunity, eq. (5), to forward that Data message. Conversely, the PIT entries are only created by the nodes that



(a) (b) (c)

FIGURE 5. **Number of forwarded *data* messages in the network for varying (a) T_r, (b) N, and (c) λ. (a) λ = 1s, 2s and N = 49 nodes. (b) λ = 1s, 2s and T_r = 140m. (c) T_r = 100m, 200m and N = 49 nodes.**



(a) (b) (c)

FIGURE 6. **Interest satisfaction ratio for varying (a) T_r, (b) N, and (c) λ. (a) λ = 1s, 2s and N = 49 nodes. (b) λ = 1s, 2s and T_r = 140m. (c) T_r = 100m, 200m and N = 49 nodes.**

forward the Interest in the proposed scheme, which reduces the chances of Data message to be forwarded by many nodes. Impact of transmission range, network size, and inter Interest interval on the total number of Data messages processed in the network is shown in Fig. 5a, Fig. 5b, and Fig. 5c, respectively.

Against the proposed scheme, conventional scheme forwards less number of Data messages as T_r increases, refer Fig. 5a. The reason behind this phenomenon is a large number of nodes that have respective PIT entries, size of Data message, and equal chance to forward the Data message. Hence, the Data messages are dropped in the network and could not reach the consumer node, as discussed later in this section that interest satisfaction ratio is very less for the conventional scheme. Because of less number of nodes with PIT entries, the small number of Data messages are forwarded in the network by the proposed scheme. Increase in the T_r results in large node density that naturally increases the number of nodes to forward Data messages. Even in this phenomenon, the proposed scheme reduces Data message broadcast for about 41.75% in the varying T_r scenario, Fig. 5a. Similarly, the proposed scheme reduces 33.7% and 31.35% of the Data message broadcast than the conventional scheme for the case of varying N (Fig. 5b) and λ (Fig. 5c), respectively.

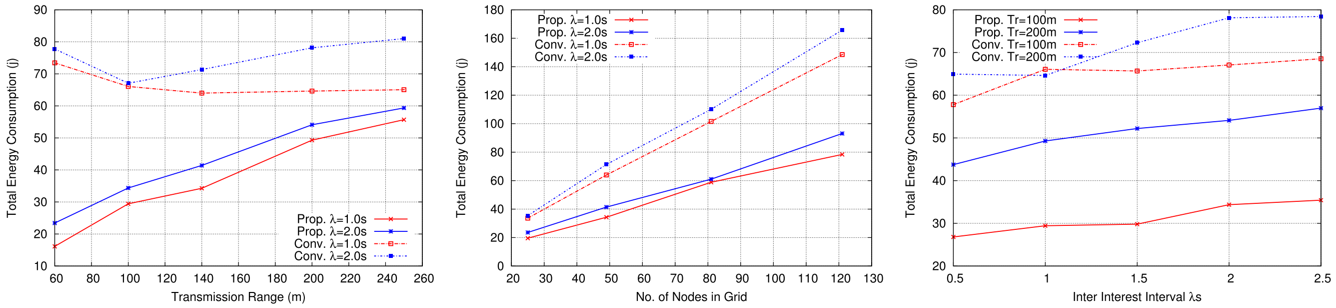
3) INTEREST SATISFACTION RATIO

Figure 6 shows the Interest satisfaction ratio investigated for different T_r, N, and λ in Fig. 6a, 6b, and 6c, respectively. As per previous discussions, the conventional scheme has high Interest-Data message traffic that causes more packet loss. Even after 4 retries, the successful reception of the first Data message for an Interest is for more less than the proposed scheme. The proposed scheme on the other side, comparatively generates less Interest-Data traffic due to parameters $d_{(i,F)}$, h_i, and θ_i in eq.(1). Also, the proposed Interest-Data suppression algorithms suppress the nodes with less distance between forwarder and IR.

It is evident from Fig. 6c that the proposed scheme has a far much larger Interest satisfaction ratio than the conventional scheme. Specifically, in Fig 6c, the proposed scheme has a large Interest satisfaction ratio for small T_r and vice versa. Average Interest satisfaction ratio of the proposed scheme for $T_r = 100m$ and $T_r = 200m$ is 72.08% and 51.3% compared to Interest satisfaction ratio of conventional scheme that is 39.5% and 22.44%, respectively. The rationale behind this situation is that the conventional scheme's Interest broadcast storm doubles when T_r increases from 100m to 200m, which leads to a large Data message drop. Hence, the consumer fails to receive Data message even after 4 Interest retries. On the other hand, the proposed scheme controls the broadcast storm that forwards more data packets that successfully reach the consumer node, refer Figs. 4 and 5, particularly 4c and 5c to observe Interest-Data message trends.

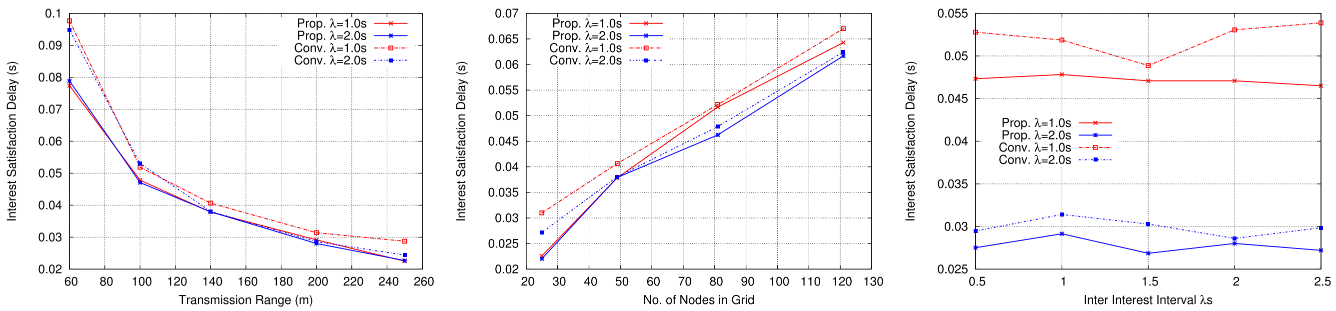
4) TOTAL ENERGY CONSUMPTION

Figure 7 shows the total energy consumed by all WSN nodes for different T_r, N, and λ. Energy consumption is



(a) (b) (c)

FIGURE 7. **Total energy consumption in the network for varying (a) T_r, (b) N, and (c) λ. (a) λ = 1s, 2s and N = 49 nodes. (b) λ = 1s, 2s and T_r = 140m. (c) T_r = 100m, 200m and N = 49 nodes.**



(a) (b) (c)

FIGURE 8. **interest satisfaction delay for varying (a) T_r, (b) N, and (c) λ. (a) λ = 1s, 2s and N = 49 nodes. (b) λ = 1s, 2s and T_r = 140m. (c) T_r = 100m, 200m and N = 49 nodes.**

TABLE 2. **Summary of performance improvement achieved by the proposed scheme.**

Scenario		Avg. # of Interests Fig. 4		% Less	Avg. # of Data Fig. 5		% Less	Total Energy (j) Fig. 7		% Less
		Prop.	**Conv.**		**Prop.**	**Conv.**		**Prop.**	**Conv.**	
$T_r = 50 \sim 250m$ $(N = 49)$ (a)	$\lambda = 1.0$	3130	11287	**72.3%**	1087	1897	**42.7%**	36.96	64.63	**42.8%**
	$\lambda = 2.0$	3172	12686	**75.0%**	1130	1907	**40.8%**	42.53	75.07	**43.3%**
$N = 25 \sim 121$ $(T_r = 140m)$ (b)	$\lambda = 1.0$	3268	15626	**79.1%**	1391	2130	**34.7%**	47.76	86.92	**45.1%**
	$\lambda = 2.0$	3213	16237	**80.2%**	1424	2116	**32.7%**	54.77	95.66	**42.7%**
$\lambda = 0.5 \sim 2.5s$ $(N = 49)$ (c)	$T_r = 100m$	2141	10935	**80.4%**	1071	2022	**47.0%**	31.17	65.03	**52.1%**
	$T_r = 200m$	4072	13913	**70.7%**	1310	1552	**15.6%**	51.26	71.68	**28.5%**

directly proportional to the number of messages (Interest-Data messages) forwarded in the network. Data messages have major impact on the energy consumption of the WSN node because of their large size. It is evident from the previous figures and discussion that the proposed scheme minimizes the number of potential forwarders and maintains less number of PIT traces in the network for an Interest. In result, it minimizes the forwarding options for the Data messages towards the consumer node and saves the battery resource. The proposed scheme successfully finds more providers by conserving battery power up to 42.8% and 43.3% for variance of T_r with $\lambda = 1s$ and $\lambda = 2s$, respectively as evident in Fig. 7a. Likewise, in the simulation scenarios depicted in Fig. 7b and 7c, the proposed scheme correspondingly consumes 45.1%, 42.7% and 52.1%, 28.5% less energy.

A comprehensive summary of the performance gains including energy conservation, forwarded Interest, and Data messages, achieved by the proposed scheme are presented in Table 2.

5) INTEREST SATISFACTION DELAY

Referring to previous description, an Interest satisfaction delay is the time duration between Interest generation by the consumer with *Name* and unique *NONCE* and reception of the first copy of the Data message (with the same *Name* and *NONCE*). Conventional scheme generates more Interests and every node that receives a copy of the Interest, keeps PIT entry irrespective of the Interest forwarding task. As a consequence, more nodes are the prospective Data forwarders. Additionally, HT_D^{Name} is a random value, which creates an equal chance for all nodes with PIT entry to be Data forwarder. This creates a high probability that the Data and/Interest message(s) follow(s) a longer path between consumer and provider nodes. Hence, the Interest satisfaction delay of the conventional scheme is higher than the proposed scheme and is discernible from Fig. 8. Interest satisfaction hop-count is shown in Fig. 9. It is logical that the number of hops between consumer-producer pair decreases with the increase in T_r. Inline with the above discussion, a large ratio of Interests is satisfied with small Interest-Data broadcast storm from less number of hops by the proposed scheme. This signifies the efficiency and effectiveness of the proposed scheme against the state of the art scheme in the literature.

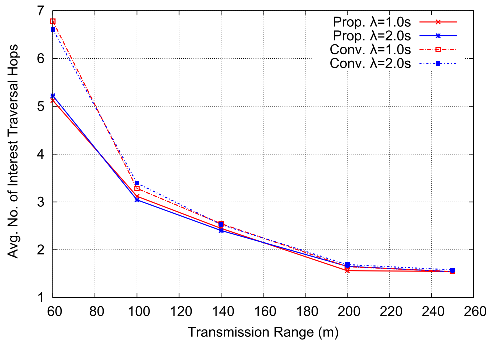


FIGURE 9. **Interest satisfaction hop-count vs T_r.**

V. CONCLUSION

Interest broadcast storm suppression scheme has been proposed in this paper. Proposed scheme employs the spatial component of content *Name* to forward Interests in the Network. It computes Interest holding time using the distance, energy, angle, and distance from the beeline between consumer and spatial region. Additionally, the modified Interest forwarding algorithm minimizes Interest broadcast storm by avoiding additional PIT entry records at all Interest receiving nodes. During the simulation, it is observed that energy consumption is mainly affected by the Data messages due to their large size. Therefore, not only the Interest but the broadcast of Data messages should be minimized to conserve network energy in the Interest broadcast phase. In future, we intend to propose a broadcast phase Data suppression scheme for WSNs.

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