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Design and Development of Network Coding Algorithm for IoT Devices

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ABSTRACT

The major achievement of third era computing is 'Internet of Things' (IoT). This internet of things technology provides real pervasive solutions in human life. The deployedIoTsolutions become scalable if the IoTnetworks have higher throughput and minimum power consumption. In this work the network coding mechanism is integrated with IoT architecture which enhances the throughput and minimizes power of the node. The proposed idea is deployed in a real-time deployable simulator called cooja simulator with ContikiOS. In this module, simple butterfly architecture has been successfully implemented with network coding. The sample network will be scaled up and verified for enhanced metrics in the second phase of this work.

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INTRODUCTION

The Internet of Things (IoT) will likely be one of the most important technological breakthroughs of the years to come. IoT could be conceptually defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network (Vermesan *et al*., 2011).In the IoT, smart things/objects are active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information sensed about the environment, while reacting autonomously to the real/physical world events and influencing it by running processes that trigger actions and create services with or without direct human intervention.

Unfortunately there are major factor to consider about the data processing in the thousands of internet thing devices wants to communicate effectively, Internet isn't just one network which includes heterogeneous networks, and reliable bidirectional signaling is essential for collecting and routing data between devices. Devices may communicate with server to collect data, or the server may communicate with the devices, or maybe those devices can communicate with one another. No matter what the case, data needs to get from one end to other end quickly and reliably with no delay.

Thousands ofIoT devices signaling and sending data between one another consume more power and CPU consumption. With all this communication capability, there is a need of minimal battery drain and low power consumption. Great battery power to small embedded IoT devices is not affordable.

For this purpose, in this work a new approach is made to improve throughput and reduce in huge network. Network Coding is the one key technology that is useful for this issue, and it not only increases the throughput but also the lifetime of the network.

1. *Methodology:*

Network Coding:

Network coding is a technique which can be used to improve a network's throughput, scalability and efficiency. Instead of simply forwarding the packets of information they receive, the nodes of a network combine several packets as a single packet for transmission. This can be used to maximize the possible information flow in a network.Network coding is a relatively new technology proven to be effective in improving the throughput and energy efficiency. Network coding can be divided into three parts (i.e., encoding at source node, re-encoding at intermediate nodes, and decoding at receivers)(Wand *et al*., 2014). Encoding and re-encoding are used to linearly mix original packets or received packets, so any encoded packet may include the information of

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multiple original packets. For this reason, network coding can be grouped under data fusion.

RPL & its Features:

IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) is a routing protocol specifically designed for Low power and Lossy Networks (LLN) compliant with the 6LoWPAN protocol (Gaddour *et al*., 2012). It operates in large scale networks having tiny devices of low power and low cost communication technology. Goals are to minimize memory requirement, low complexity in routing, data forwarding mechanisms, reduce routing signals, use compact routing algorithm and efficiently discover links and peers. RPL is more optimized for data acquisition network.

Auto-configuration: As RPL is compliant with IPv6, the RPL-based LLN will benefit from basic IP routing characteristics mainly the dynamic discovery of network paths and destinations. This feature is guaranteed by the use of the Neighbour Discovery mechanisms.

Self-healing: RPL proves its ability to adapt to logical network topology changes and node failures. In fact, links and nodes in LLNs are not stable and may vary frequently. RPL implements mechanisms that choose more than one parent per node in the DAG to eliminate/decrease the risks of failure.

Loop avoidance and detection: A DAG is acyclic by nature as a node in a DAG must have a higher rank than all of its parents. RPL includes reactive mechanisms in order to detect loops in case of topology change. In addition, RPL triggers recovery mechanisms (global and local repair) when the loops occur.

Independence and Transparency: As in the IP architecture, RPL is designed to operate over multiple link layers. RPL is able to operate in constrained networks or in conjunction with highly constrained devices. Thus, RPL is then independent from data-link layer technologies.

Multiple edge routers: It is possible to construct multiple DAGs in an RPL network and each DAG has a root. A node may belong to multiple instances, and may act different roles in each instance. Thus, the network will benefit from high availability and load balancing.

Working Principle:

Network Coding facilitates reductionof delay in deliveries and thus improves throughput in a highly dense network.There have been studies on the network lifetime in WSNs using Network Coding. Enhanced Encoding Algorithm (EEA) for network coding process with minimum energy is proposed in (Venkatalakshmi *et al*., 2012). Only limited nodes in the network do network coding. The suitability of the node to do network coding is based on its position in the network and only these optimal position nodes contribute network coding. Also only limited packets called optimal packets undergo the network coding based on their structure of flow. EEA allows the network coding conditions to be verified with the dynamic topology.

Implementation of a two-way relay network based on the principle of physical-layer network coding (PNC) is proposed in (Lu *et al*., 2013). PNC systems in which the relay performs XOR or other denoising PNC mappings of the received signal have the potential for significantly better performance. Their experimental results show that symbol-synchronous and symbol-asynchronous FPNC (frequency domain) have essentially the same BER performance for both channel coded and unchannel coded. Maximizing the benefits of network coding for unicast sessions in lossy wireless environments is proposed in (Zhang and Li, 2009). They propose Optimize Multipath Network Coding, a rate control protocol that dramatically improves the throughput of lossy wireless networks.

Bounds on the Throughput gain of network coding in unicast and multicast wireless network is proposed in (Liu *et al*., 2009). The survey shows that network coding and broadcasting lead to at most a constant factor improvement in per node throughput. For the protocol model, it provides bounds on this factor. It also establishes bounds on the throughput benefit of network coding and broadcasting for multiple source multicasts in random networks. Finally, for an arbitrary network deployment, it shows that the coding benefit ratio is at most O(logn) for both the protocol and physical communication models.

Modeling throughput gain of network coding in multi-channel multi-radio wireless ad hoc networks is proposed by Hang Su *et al*., (2009). This paper models the throughput gains of both the conventional NC and analog NC schemes over the traditional non-NC scheme in multi-channel and multi-radio wireless ad hoc networks.

Network coding schemes in which information flows propagate along a combination network topology as combination network coding (CNC) based on the link capacity which concludes the potential for CNC to improve throughput and to reduce routing cost is proposed in (Maheshwar *et al*., 21012). Finally result shows natural step towards improving the bound of 2 proved for the coding advantage of general multicast network coding**.** The study of performance of network coded cooperative diversity systems with practical communication constraints is proposed in (Iezzi *et al*., 2012). More specifically, they investigate the interplay between diversity, coding, and multiplexing gain when the relay nodes do not act as dedicated repeaters, which only forward data packets transmitted by the sources, but they attempt to pursue their own interest by forwarding packets which contain a network-coded version of received and their own data. And they provide a very accurate analysis of the Average Bit Error Probability (ABEP).

The focus of the present work is to estimate the increase in throughput in the highly denseIoT devices based on node density.

Network Model:

In this work, a mechanism of network coding for the IoT devices has been implemented. A simple IoT setup is designed with 7-nodes. The network is modeled as sample butterfly structured network as shown in figure 1. The network scheme in the designed model is in such a way that there are two client nodes transmitting their sensed data to the sink node. The network follows a routing protocol called Routing Protocol for Low power and Lossy network (RPL). Here the clients capture the data and forward them using RPL, to the sink. During their multi-hop transmission, the intermediate nodes are designed to do network coding. Once when the node realizes that it is an intermediate node, it checks for the uniqueness in the data received. Then the intermediate node combines the packets by simple Exclusive-OR function. This ensures the throughput increase at the sink node.

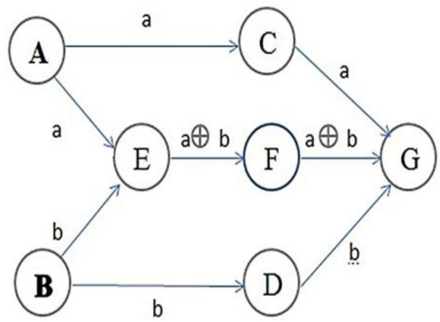

Fig. 1: Network Model

2. Simulation Results:

This work uses Contiki OS and Cooja simulator for IoT implementation. The nodes selected are SKYmote in cooja simulator. Except node 'G' others are configured as clients. The node 'G' is configured as sink. When nodes A and B capture any data, they forward in the radio read range. The nodes self-analyze for the status of mode of work. And nodes E and F self realizes that they are the intermediate nodes. Thus node E executes entire algorithm of Figure 2.

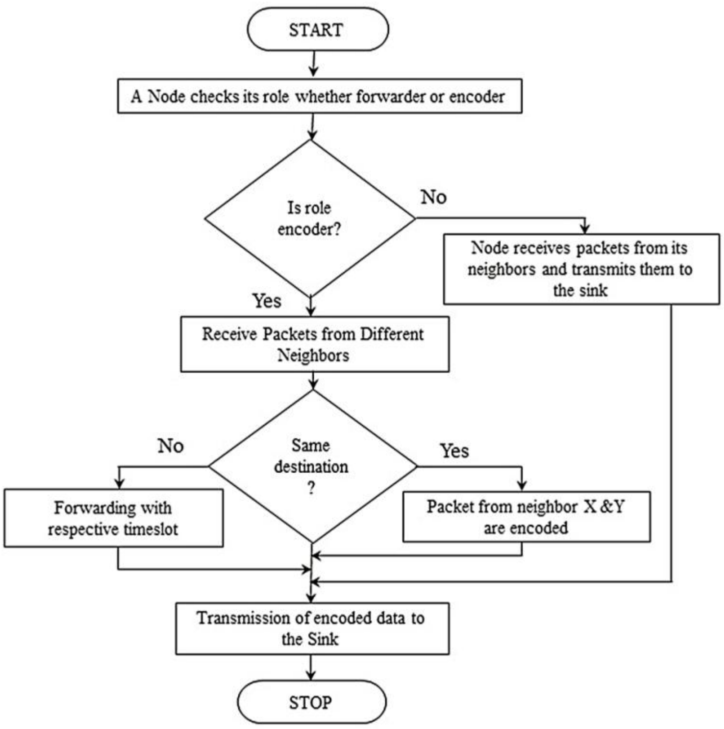

Fig. 2: Functionalities of Intermediate Node

Thus node 'E' Ex-OR the packets and node 'F' simply forwards the Ex-ORed the incoming data. Thus a simple network coding is done at node 'E'. When the data from the clients A and B are a_i and b_i then E computes the output as

$$X = a_i \oplus b_i \quad \text{where i= (1,2,3,…n)} \qquad (1)$$

Thus the output of node 'E' is X and is transmitted through node 'F' to the sink node 'G'. At 'G', the data is decoded for recovery by following function as

$$Y = X \oplus a_i \quad \text{where i= (1,2,3,…n)} \qquad (2)$$

The Ex-OR function at E and G, follows the algorithm as shown in figure 3.

Network Coding Algorithm:

Source Algorithm:
Input: message[n]
Output: s_buffer[n], node_id

1. Start the process of establish connection at nodes
2. Input sensor data move to character array
Message[n] = input data
3. Convert character to binary function S_buffer[n] = ASCII_char_to_bin(message[n])
and move to s_buffer[n]
4. Send to the connected node in the network s_buffer[n]
5. Output as (s_buffer[n], node_id)

Intermediate Node algorithm:
Input: r_buffer
Output: f_buffer

1. Receive data from source
2. Verify node_id, data length
3. Checkifdata_length = 1(full) from intermediate node. Go to step 4
4. Else wait for the message (data). Go to step1
5. Move r_message[node_id] = r_buffer[n]
6. Verify node_id as if node_id=1, move r_message[node_id_1] = r_buffer[n]. Else r_message[node_id_1] = r_buffer[n].
7. Check if both node_id message received as r_message[node_id_1] and r_message[node_id_2] are full
Else go to step 1
8. Go to function encode
a. Str_1[] = r_buffer[n] from node_id_1
Str_2[] = r_buffer[n] from node_id_2
b. For y range from string length of str_buffer[] to null character(i.e., '\0')
i. Xor[x] = str1[x]^str2[x];
ii. Return Xor[x]
9. Move to s_buffer == Xor[x]
10. Send to receiver node as (s_buffer,node_id).

Receiver Algorithm:
Input: r_buffer[n], node_id

1. Receive data from node with r_buffer, node_id
2. Verify node_id, data length
3. Check if data_length = 1(full) from node
Else goto step 4
Else wait for the message (data)
Goto step 1
4. Move r_message [node_id] = r_buffer[n]
5. Check if both node_id message received as r_message[node_id_1] &r_message[node_id_2] are full
Else goto step1
6. Go to function encode
a. Str_1[] = r_buffer[n]
Str_2 [] = r_buffer[n]
b. For y range from string length of Str_buffer[] to null character (i.e '\0')
i. Xor[x] = str1[x]^str2[x];
ii. Return Xor[x]
7. Convert from binary to ASCII character message_r[n] = bin_to_ ASCII_char (Xor[x])
8. Display message_r[n]
9. End

If node D fails, thus the sink node can able to know the B nodes' packet with no need of retransmission from node B. Thus improves the reduction of power consumption and delay which drastically improves network lifetime.

The snapshots of the simulation are shown in Fig. 4, 5 and 6 respectively.

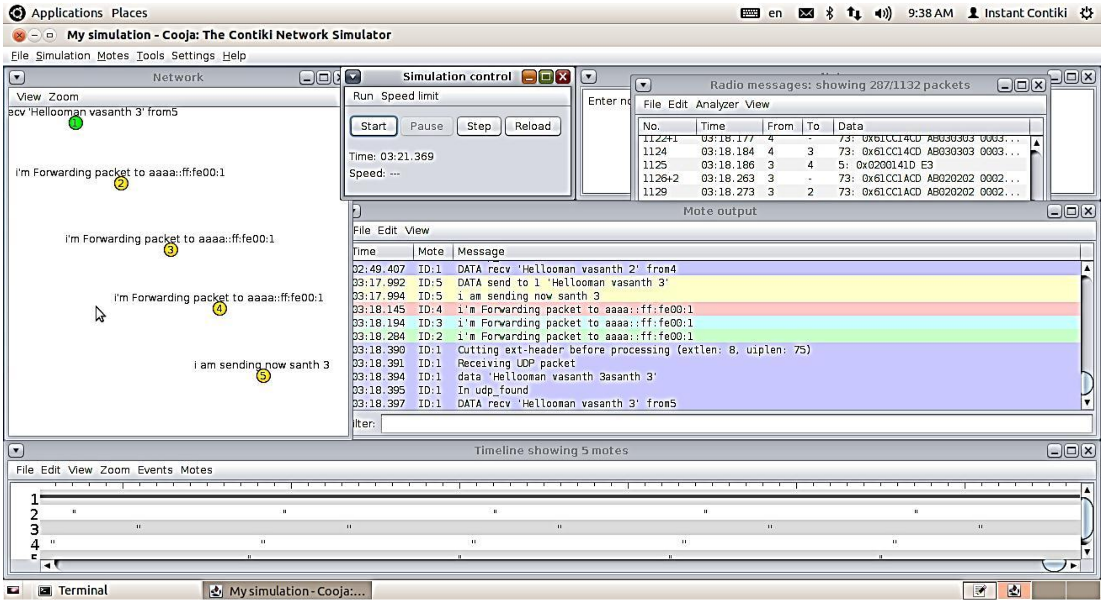

Fig. 3: Forwarding Node

Node 5 sends message to the sink node 1 through node 4, node3 and node 2 respectively and thus the intermediate nodes depicts that they do forwards the incoming packets which is originated from source node is shown in Fig. 3.

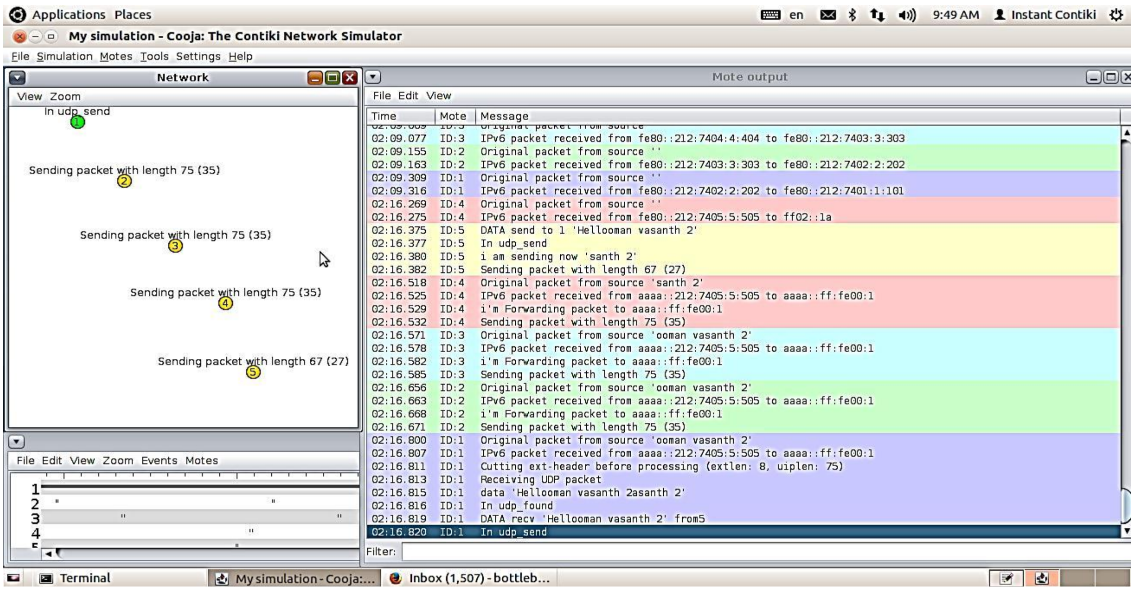

Fig. 4: Realizing Forwarding nodes

Detailed description of the incoming packets size and its originating nodes are sensed and detailed in forwarding nodes in the mote output window ofcooja simulator as shown in Fig. 4.

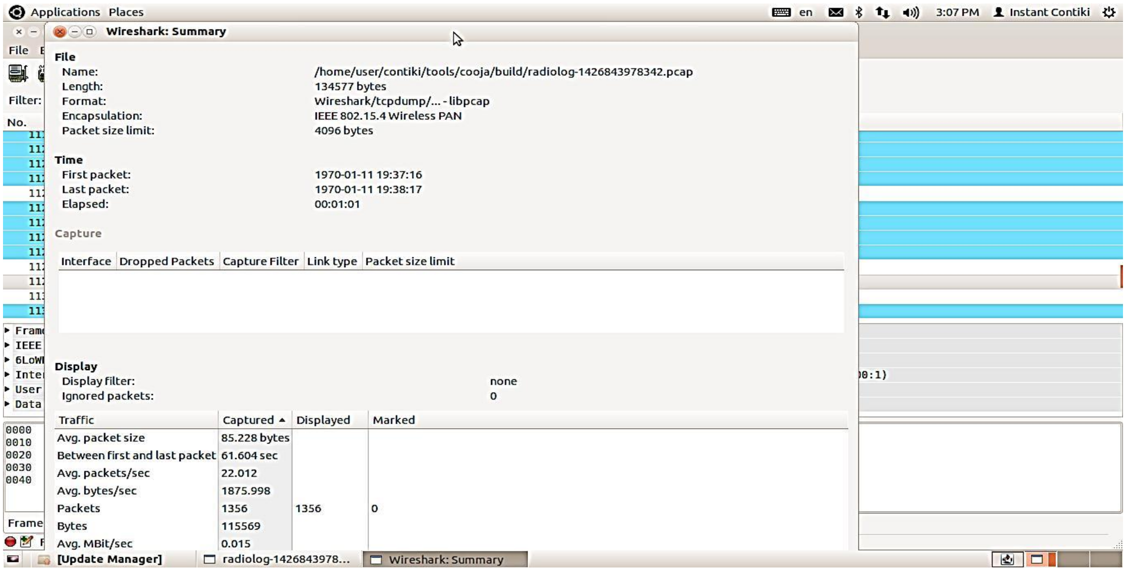

Fig. 5: Large Network with Wireshark

Throughput is calculated using the network protocol analyzer called wireshark and it is shown in Fig. 5.

Conclusion:

The work ensures the benefit of network coding in real time networks of IoT. Also under un-reliable paths, the path resilience is retained with minimal delay. The encoding node has a trade-off in the computational power of the node with the throughput. The future work will design the optimal power algorithms for the nodes through minimal network coding mechanisms.

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