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D2D Communication in 5g for Internet of Things

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ABSTRACT: Since we have the structure blocks for an IoT mesh network, fabricating a practical network arrangement to have devices convey to the serving network is a necessity. Choosing a frequency range for general D2D IoT communicationthat is outside the authorized range, understanding what the limitations of that frequency ranges are, and afterward assembling some practical simulations to test if the theory is sound, will expose future inquiries to reply or demonstrate that mesh networkscan be effortlessly evolved.First, we will comprehend what frequency rangesare permitted to be utilized. If we can utilize a frequency range that is outside the authorized range, we can permit these devices to set up automatically and create routing arrangements that are moderately optimized relying upon node-to-node connectivity.Second, we will build up the methodologyof building the network. Taking into account that in the upcoming age of radio access we're expecting arrival at the serving network to be more difficult for radio access for a majority of the network spaces, we ought to consider a huge sensor networkor security system up-linking through a few devices compared with the larger mesh.

Keywords: IoT (Internet of Things), D2D (Device to Device),Frequency, Routing, Network.

I. INTRODUCTION

Here we will go through a short background on the requirements of ProSe (Proximity Services) [1](D2D) connections between devices, the power, and message flow requirements, separation of the Application Server (AS) [2] requirementsfrom those messages, and then set up of mesh style networks in places where serving networks are absent. We will then look at the power requirementsof these connections and how allowing ad-hoc 5G ProSe networks [3]allows for lower power requirements of devices. We'll then explore how these lower power requirements can affect the designs of the devices themselves and their uplinks to the internet.

While most homes or businesses do not have issues with network connectivity, basements and larger buildings may not have network connectivity to a 5G tower in MM (milli-meter) Wave [4] setups. In these cases, internet-of-things (IoT) setups should be allowed to set up in semi-licensed or unlicensed spectrum without authorization from the serving network. To let it happen, in certain cases, the ProSe requirement of an Application Server can be relaxed so that if the devices are unable to connect to the serving network, they can still establish a D2D link.

To facilitate the ad-hoc network setup, we will explore how the devices discover each other, channel scanning and selection, power requirements, and nomination/selection of uplink nodes back to the serving network [5], either via 5G cellular network [6], wifi, or wired connection. Then we'll move through several node scenarios to show how the network reacts to new nodes arriving and leaving the network space.

II. LITERATURE REVIEW

This article presents a definite and precise review of resource allocation, interference management, and mode selection in D2D communication. At first, the scientific categorization-based outline of D2D communication is given, and the grouping of the work is laid out. Then, the works concerning mode selection are explored in detail. [7]

This article showed an outline of how intelligent D2D communication can be accomplished in the IoT environment. Specifically, it centers around how best in class routing algorithms can accomplish insightful D2D communication in the IoT. [8]

This article addresses the market-changing phenomena of the Internet of Things (IoT), which depends on the fundamental paradigm of machine-to-machine (M2M) communications to coordinate plenty of different sensors, actuators, and smart meters across a wide range of organizations. Today the M2M scene includes an outrageous variety of accessible connectivity solutions which, because of the huge monetary guarantee of the IoT, should be blended across different enterprises. [9]

This article gives a thorough review of emerging and enabling technologies identified with the 5G framework that empowers IoT. It considers the innovation drivers for 5G wireless technology. It additionally gives a review on low-power wide-area networks (LPWANs), security difficulties, and its control measure in the 5G IoT situation. [10]

III. METHODOLOGY

1. Frequency Ranges for IoT Setup

To enable the mesh network to setup, we must either allow the IoT devices to use licensed bandwidth or designate some portion of the semi-licensed spectrum for inter-IoT device setup. We can use the upper end of the designated 5G spectrum [11], which is not practical for serving network access, for connections between IoT devices.

Since the range in most relay applications isn't very high, the 64-71GHz can be utilized. If we estimate 70 MHz per connection, we can enable a 100-channel set up in the 7 GHz of bandwidth, which should be enough for a large majority of device layouts and enable a large number of high throughput video devices. Depending on the throughput requirements of each one of those devices, the channel size could be reduced greatly down to the standard 20 MHz, allowing for several additional channels.

The high-power loss over distance also reduces the problem of co-channel interference in the case of mesh networks being near each other but not close enough to develop connections. When a device is installed and powered on, the first thing it will do is scan the surrounding frequency spaces [12] and then select a channel that is not currently used.

2. Power Model Selection & Formula

Using standard power loss calculations, we can calculate the power loss at 1 meter, which is about 45 dB (15 dBm) for the 64 to 71 GHz. We use the following formula to determine that:

$$P_L(d_0 = 1m) = -10 * \log\left(\frac{G_t * G_r * \lambda}{(4 * \pi)^2 * 1^2}\right)$$

We will be assuming the transmitter and receiver gain as 1 to establish baselines.

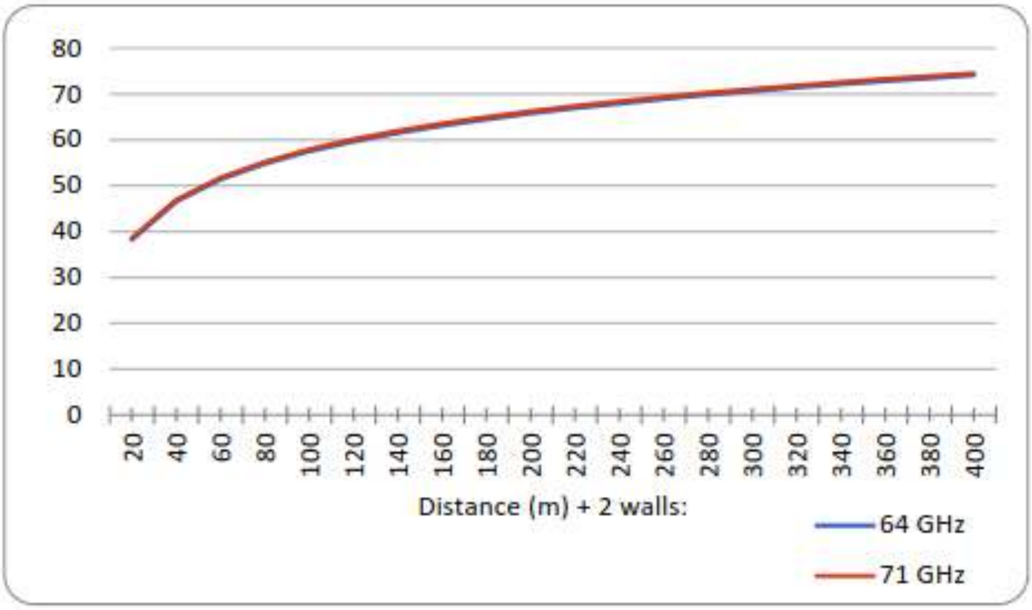
Performing these calculations, we can see that the difference between the frequencies at 64 GHz and 71 GHz is very small (45.27 dB and 45.73 dB).

We then can use the indoor power model to calculate the power loss between devices. We will be using two calculation models in the simulation.

1. If the devices are on the same floor.
2. If the devices are on different floors.

For the devices on the same floor, we'll assume there are 2 walls (5 dB loss on each) between the devices and a mean loss exponent of 2.76. We'll assume transmit power of 23 dBm (Standard).

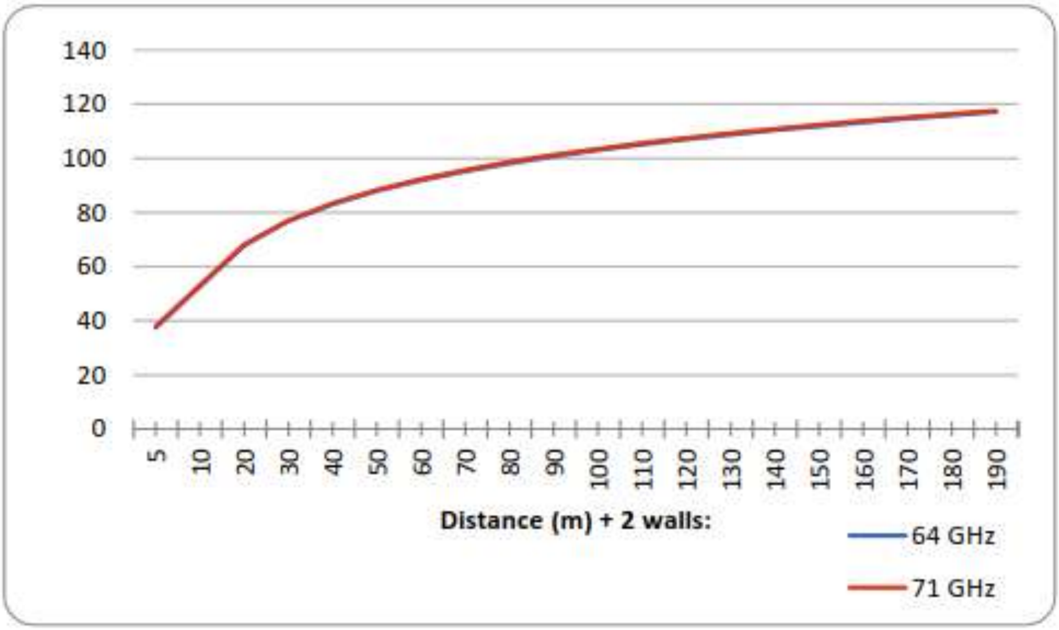
$$P_L(d) = 15.27 + 10 * 2.76 * \log(d) + 2 * 5 - 23$$



Power Loss Between Devices on the Same Floor

For the devices on a different floor, we’ll assume there are 2 walls (5 dB loss on each) between the devices and a mean loss exponent of 5.04. We’ll assume transmit power of 23 dBm (Standard).

$$P_L(d) = 15.27 + 10 * 5.04 * log(d) + 2 * 5 - 23$$

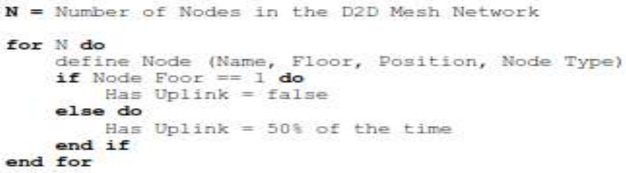


Power Loss between Devices on Different Floors

3. Creating the Mesh Network in Matlab Simulation

We will use functions to step through the configurations [13] and make determinations around power requirements and connections. After creating the nodes in random positions, if the distance P_L between devices is less than 115 dBm, we will assume that the devices can talk to each other. In most scenarios, this would mean that all the devices on the same floor can communicate with all other devices whereas only nearby devices can communicate between floors.

In our case, a 2 story, 100m by 100m building was randomly seeded with devices. On the lower floor, it was assumed that none of the devices would be able to talk to the serving network, simulating a basement or a metal building's lower floor with no windows. On the upper floor, a 25% chance was given to allow for a serving network connection, simulating a device either being close to an outer wall, having LOS to a serving network site, or having some sort of wifi bridge or hardwire connection in the case of larger multi-purpose nodes.



```
N = Number of Nodes in the D2D Mesh Network

for N do
    define Node (Name, Floor, Position, Node Type)
    if Node Foor == 1 do
        Has Uplink = false
    else do
        Has Uplink = 50% of the time
    end if
end for
```

Code for Node Random Generation

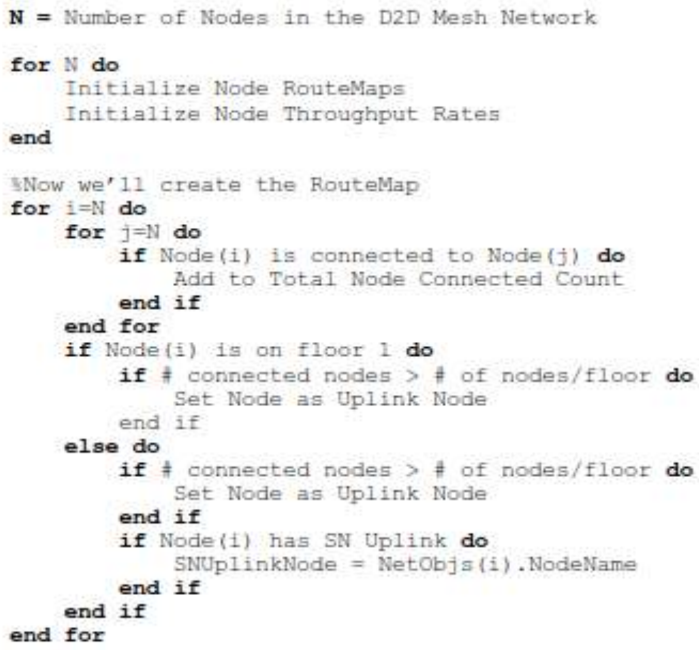
We then generated a set number of nodes with random positions and floor locations. At lower node counts (less than 8), their power requirements led to a lot of mesh networks that were not able to serve all the devices. At 8 nodes, over 50% of the time, a network randomly generated was viable. This doesn't imply that lower node-setups are invalid, but that careful planning would be required for them to be viable.

As we increase the node count further to generate larger networks, once over 10 nodes, almost 100% of the networks were viable. We then tested the setups of those networks to determine routing and power requirements.

4. Routing Criteria & Uplink Node Selection

When building a 5G IoT network, the intention isn't so much to have the nodes sending application data to each other, but instead sending application data to servers on the internet for processing or for sending or receiving video or audio streams from the internet to or from the end devices. Because of this, the original application server requirements can be relaxed.

To facilitate this communication [14], some sort of routing protocol must be used. In our case, since all the nodes can talk to all other nodes on the same floor, but nodes in between floors can only talk to each other at very specific distances, the node connection parameters were compared to determine which nodes could talk to the nodes on different floors.



```
N = Number of Nodes in the D2D Mesh Network

for N do
    Initialize Node RouteMaps
    Initialize Node Throughput Rates
end

%Now we'll create the RouteMap
for i=N do
    for j=N do
        if Node(i) is connected to Node(j) do
            Add to Total Node Connected Count
        end if
    end for
    if Node(i) is on floor 1 do
        if # connected nodes > # of nodes/floor do
            Set Node as Uplink Node
        end if
    else do
        if # connected nodes > # of nodes/floor do
            Set Node as Uplink Node
        end if
        if Node(i) has SN Uplink do
            SNUplinkNode = NetObjs(i).NodeName
        end if
    end if
end for
```

Code for Uplink Node Determinations

Once these are determined, we use a function to walk through the connected node variables to fill out a route map for each node. This route map will be used when we determine what the bandwidth requirements are for each of the connections between the nodes to serve its traffic and any traffic through the node to the nodes that it is servicing.

5. Bit Rate Calculations and Throughput Requirements

Now that we have a route map via uplink nodes and connections to the serving network, we can start to calculate the bit rate requirements [15] for the inter-node communications.

In an average 8 node setup, each uplink node will talk to 4 other nodes (if there is a 50/50 split on floors). The first-floor uplink node will talk to the 3 other nodes on the same floor and the node it can communicate to on floor two, and the second-floor node will talk to the 3 other nodes on the same floor and the node it can communicate to on floor one.

Similarly, the serving network uplink node(s) will talk to other nodes on the same floor and have all traffic to and from the serving network relayed through it. The code runs through the connected node maps and adds the first-floor or second-floor uplink nodes for the nodes not populated. This allows each node object to having a next hop for all nodes in the network.

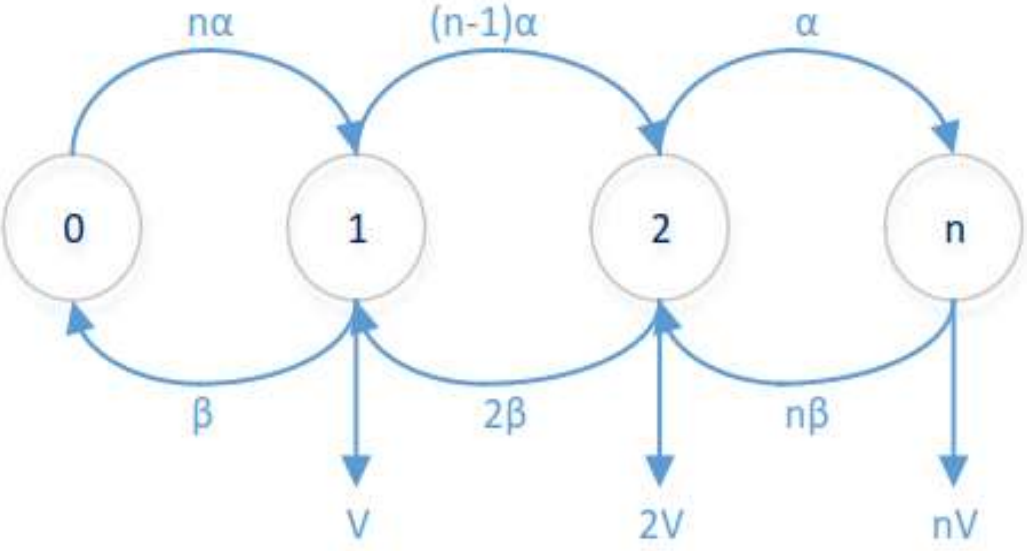
After creating the route map, we can then calculate the data rate requirements for each node with randomly generated network objects. In the code, we set a random variable to determine what kind of object each network node is and what kind of data it would either be sending or receiving. We will walk through each node and use that variable to set the bit rate generated by that node to and from the mesh network.

Now that we have determined what the bit rates are to and from the serving network for each one of the devices, we can create the total traffic pattern for the entire mesh network. It will give us the total bit rate in and out of every node in the serving network. Then, we'll determine the queuing model for the nodes to determine how a larger number of nodes affect transmit/receive capabilities and service time.

6. Queuing Model & System Time Calculations

Now we have to understand what pushing this traffic through the network does to each node's transmission requirements. We'll model this via Fluid Source Modeling of a bursty traffic model.

First, we need to assume some variables. We'll assume that the on-time (α) for this traffic is 2 seconds and the off-time (β) for this traffic is 0.5 seconds. The transmission size per state will be the total traffic relayed through the node divided by the number of nodes on that the relay node is serving. That gives us a Markov diagram like:



Markov State Diagram for Fluid Traffic Analysis

Now that we've defined the state diagram, we can develop the equations to determine queue time and possible packet loss. If we're modeling this like a video source, we can be using 20 mini sources and the following equations:

$$P = \frac{\alpha}{\alpha + \beta} \qquad k = \frac{\beta x}{Rp(1-P)\ln\left(\frac{1}{PL}\right)}$$

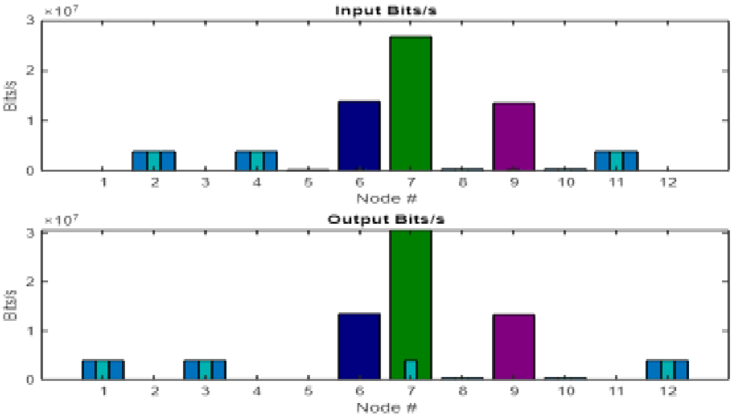
$$\frac{CL}{Rp * N} = \frac{1-k}{2} + \sqrt{((1\text{-}k)/2))\text{^}2\text{+}k\text{*}P)}$$

With the results from these equations, we can determine what additional latency would be introduced via the relay mechanism and how modifying each of these variables will affect the total traffic. We can also determine how large the networks can get before this mesh setup stops working.

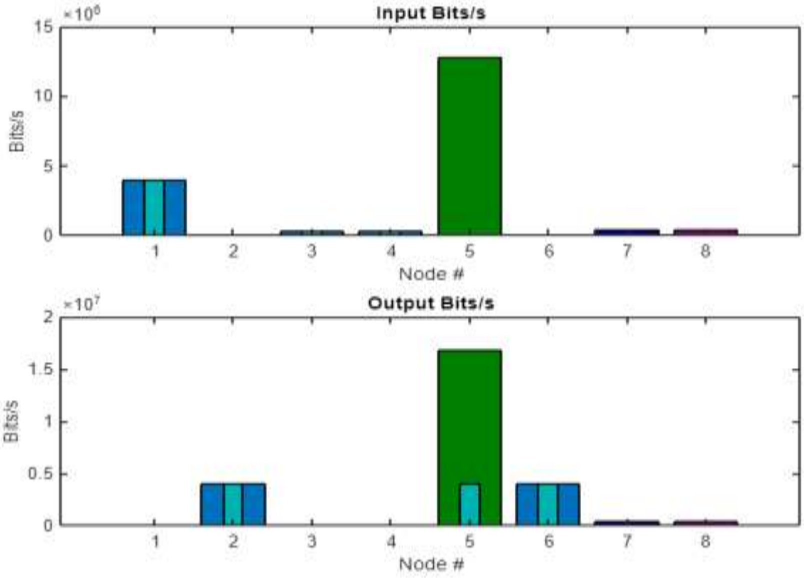
IV. SIMULATION RESULTS

1. Bitrate Requirements Per Node

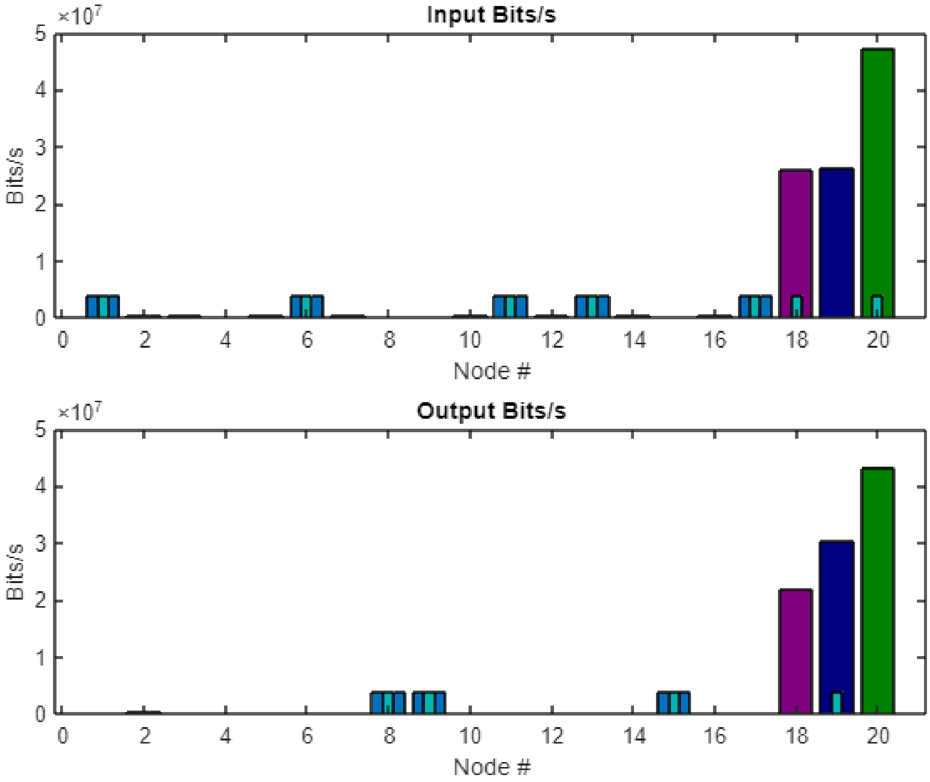
The simulated network output can now be graphed by the number of nodes and their Input/Output requirements. We can see that there are no issues with actual throughput of any device on a per-channel basis.



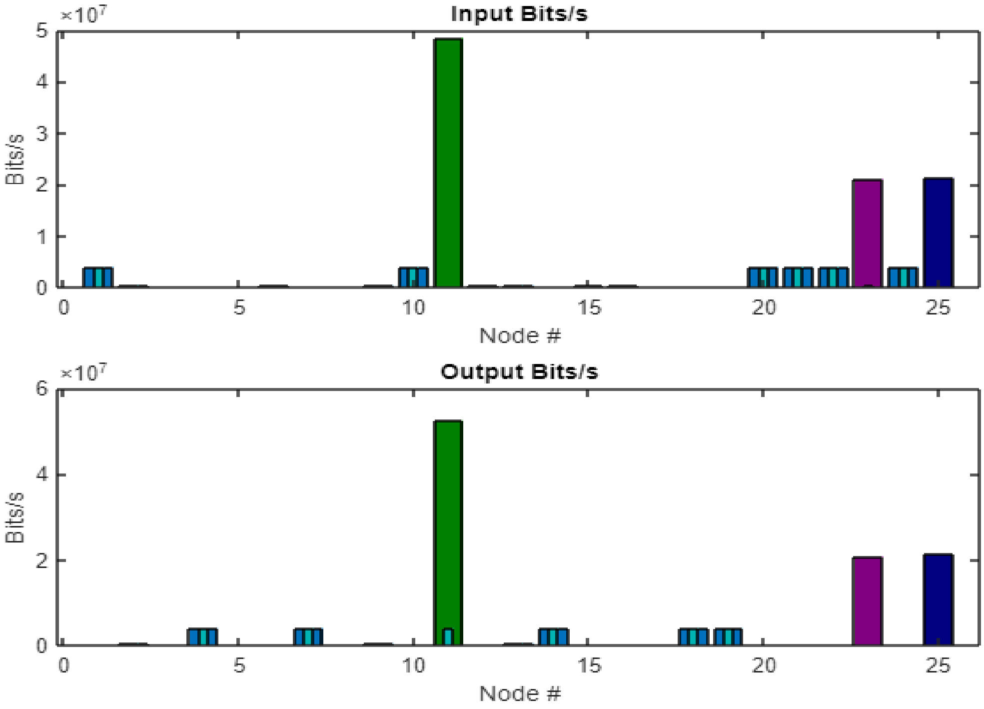
12 Node Bit Rate Input/Output



8 Node Bit Rate Input/Output



20 Node Bit Rate Input/Output



25 Node Bit Rate Input/Output

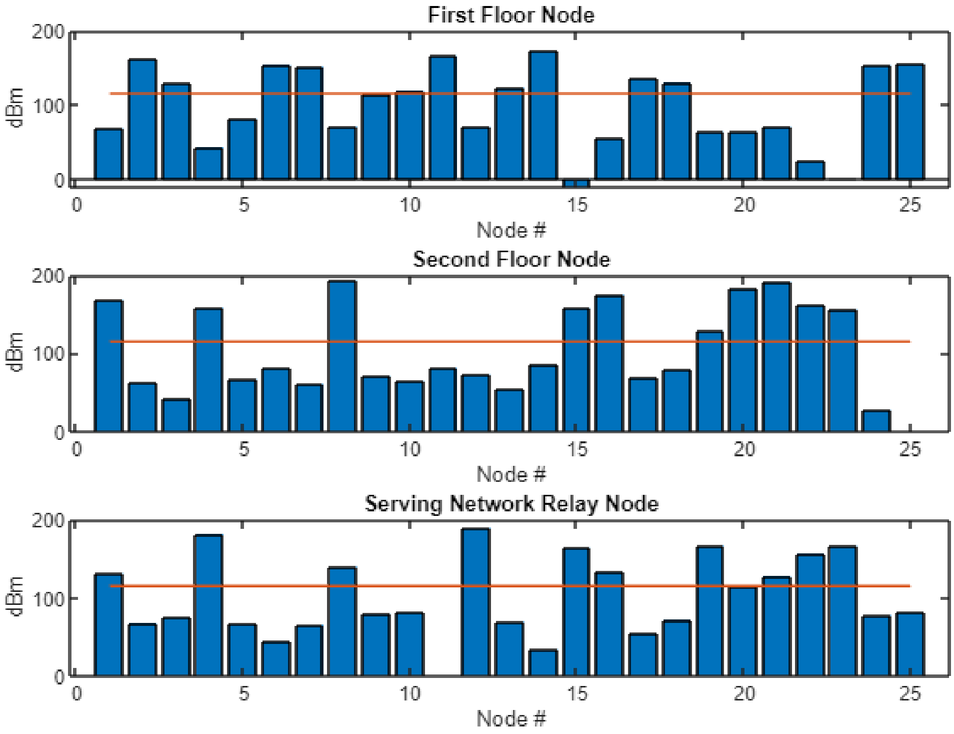
The green nodes represent the uplink nodes, and the purple nodes represent the uplinks to the first floor. In the simulation, we find that N node configurations require N channels between each of the uplink/relay nodes. In smaller node configurations like 8, this is manageable, but it becomes complex for larger configurations.

This can be managed either by changing the routing algorithm to reduce the number of channels per node or by developing some sort of hub node to enable a large number of channels per device for those relay nodes.

2. Power Requirements

The advantages of the above configurations are evident as well. The average power requirements of the channels set up between devices on the same floor are much lower than connections on the devices between floors or the connection between the uplink nodes and the serving network.

We can observe that the power requirements for nodes on the same floor are very well under the 115 dBm limit while the ones on different floors are either very close to the 115 dBm limit or are well above the 115 dBm detection threshold.

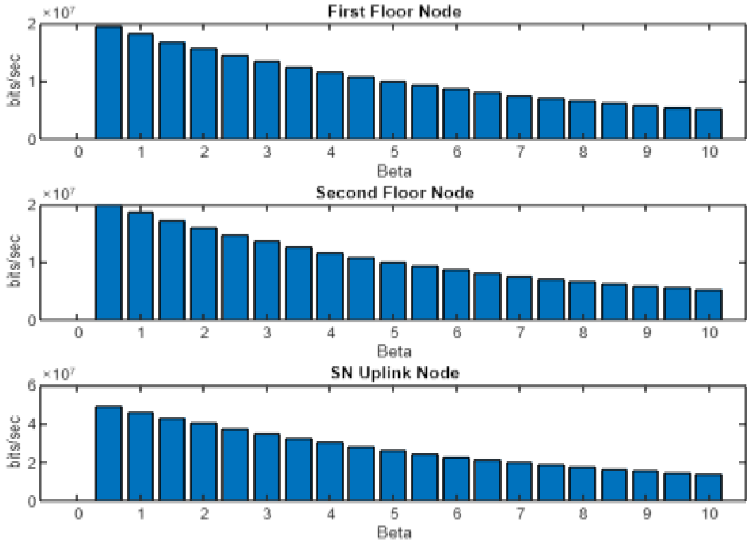


25 Node Power Connection Levels

3. Queuing Model

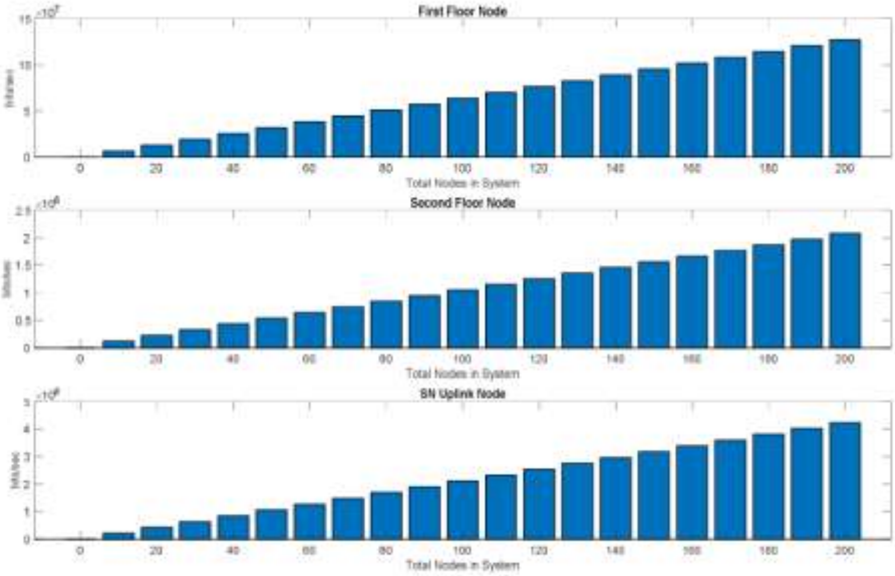
We can see that by varying the beta from 0.5 to 10, we can considerably reduce the number of bits required per second. It will reduce the required power and increase the efficiency of the network.

Alpha = 2, Buffer = 4 Meg, Number of Nodes = 25, Beta Varied Between 0.5 and 10.



The following graph shows the total number of nodes being varied from 0 to 200. We can see that even with an order of magnitude of more nodes, we are still well within the design specifications of the 5G network.

Alpha = 2, Buffer = 4 Meg, Number of Nodes Varied Between 0 to 200, Beta = 0.5.



Throughput vs # of Nodes

4. Nodes Entering or Leaving the Network

The final thing to be looked at was the disruption of the network when nodes enter or leave the network. As long as the nodes leaving or entering the network are not any of the 3 targeted relay nodes that all the nodes communicate through, the amount of traffic will fluctuate, but the structure of the network will remain intact.

If one of the relay nodes leaves, the network must be notified and the whole process needs to be re-run to update the routing tables and to update the next-hop for all the nodes for its traffic to either reach the node or the serving network.

There is also a small possibility, especially in smaller configurations that the new network structure (after the addition or deletion of a node) will not be a valid mesh network because either the nodes won't be able to talk between floors, or because all links are removed to the serving network.

V. CONCLUSION

As we can see, a practical setup of mesh networks considering large numbers of nodes is relatively straightforward to simulate. Power requirements are lower and devices that could normally not get to the serving network now can.

What we have found is that the D2D concept itself is sound for low numbers of nodes, but when establishing the mesh networks for larger node networks, more research is needed around the setup of the mesh and routing functions through it.

VI. FUTURE WORK

We can use some sort of multiplexing to treat what we would consider a single 5G channel as a wifi-like fabric instead of setting up individual channels for each connection.

Besides, dedicated forwarding chipsets, such as Application Specific Integrated Circuits (ASICs), may be required in the devices to handle the data throughput required between the nodes.

When these two research items are completed, we should be able to serve mesh networks in the simulated configuration that are upwards of 400+ nodes, with only the bit rate of the uplink to the network as the constraining factor.

The next steps of research would be verifying that this multiplexing is possible and generating a control scheme for multiplexing and routing in the network, similar to what is done in a Z-Wave (800-900 MHz) or other mesh style network setups. Then, when the data rate is determined using those methods, find what that load does to the SoCs commonly found in IoT devices and if ASICs are required for forwarding.

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