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# Graph Based Interference Analysis and Resource Allocation in mmWave IoT Networks.

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**IoT**, **Internet of Things** is one of the most promising technologies of the fifth-generation (5G). The buzz is all about creating smart environments and getting every type of device connected to the internet. 5G will revolutionize the speed at which the data is transferred, and how much can be transferred at one time. Millimeterwave (mmWave) and massiveMIMO are the two key technologies which play an essential role to address this problem and represent the next frontier of wireless technology, bringing 10 times higher frequencies and 10 times wider channel bandwidths than the most advanced Wi-Fi and cellular technologies. Millimeter-wave technology is becoming less expensive and easier to deploy, making it a candidate for many wireless connections, including backhaul, personal area networks and LANs. In the world of IoT, this translates into instant, reliable machine communication across every industry and application possible [1]. As the density of wireless devices increases and requirements of all their applications change drastically, it becomes more challenging to provide them connectivity within the stipulated amount of time to deliver the needs. As a result, several challenges such as improving the network capacity, coverage area, efficient data capturing, security, signal processing becomes a necessity to be handled. In line with these, a very recent area of research is to exploit mm-wave band for use in 5G IoT implementations unlike the traditional usage of Zigbee and Bluetooth technologies. One of the technical challenges in this broad area of research is **coordinating communication among large number of devices** ensuring highly reliable links and investigate on **the potential of Resource allocation** to envision a diverse set of usage scenarios and applications.

We systematically analyze a dense indoor Wireless Sensor Network (IoT) system, with randomly deployed sensors, operating at mmWave bands (27GHz). **Interference and Resource Allocation problems** are addressed considering a medium sized (4-5cells) IoT system as a cluster which is divided into a number of small cells (Fig 1). Small cells can benefit IoT connectivity and functionality as most IoT applications are low powered devices, feasible for short ranged applications. Moreover, mmWave bands have proven to be well suitable in small dense cells due to their propagation characteristics. Each cell is supported by a fixed set of random IoT nodes, an access point (AP) with an antennae array of *n* elements suitable for beamforming and to form a set of fixed directional beams with varying beamwidths .We investigate aspects of **Intra** and **Inter cell** Interferences from two perspectives**: Directional Beams and Channel Assignment (Frequencies)**. We proceed our research through **Graph Theoretical** approaches to study Interferences and Resource Allocation in a simplistic IoT scenario.

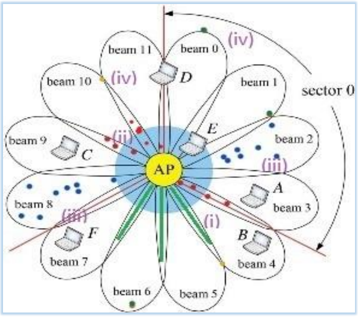

Fig 1: (a) IoT cluster with a cell size of about 500m (b) Single cell with Base station and IoT sensor

**Main Objective**: Optimal Beam and Frequency Allocation to IoT nodes (users) to achieve high user density.

**Problem Formulation:** We formulate our research contribution into two main categories.
**C1:** study on the feasibility of mmWave channel for IoT applications.
**C2:** To address Interference and Resource Allocation problem through Graphical Procedures.

**C1**: mmWave environment is analyzed for use in 5G IoT implementations and its main challenges are investigated. A simple IoT architecture with a star topology is chosen among the different types of IoT architectures explored (Fig 2). **Antenna Technology, Role of Antenna Arrays and Beamforming** are the other concepts studied in detail to apply to the scenario [2]. Selecting the antenna configuration to ensure maximum coverage from the transmitter side was another feature to be considered. Technologies such as **multi**

beam (as used in six-sector deployments), Uniform liner array (ULA), Adaptive array, Phased array, Beam-switching array allow the antenna's coverage area to be shaped and formed to fit the capacity and coverage requirements of users. The compact size of 27GHz radio permits multiple antennas solutions and makes room for beamforming and use directional beams. A radiation pattern which can create a fixed number of beams with varying, phase and weights and with the aim of attaining maximum coverage is chosen. In this regard beamforming implementation techniques such as analog, digital and hybrid beamforming types which form one of the main features of mmWave are also explored. In our scenario, fixed number of directional beams with varying beam widths are generated at the transmitter to focus the beam and adapt to a user's equipment and ensure maximum coverage while the IoT nodes (users) use an omnidirectional antenna due to their simplistic feature of size and power levels.



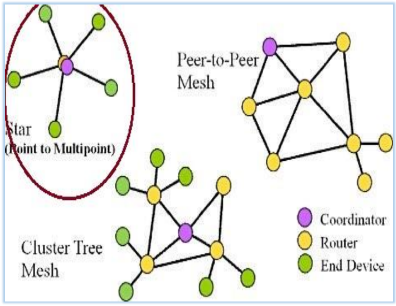




Fig 2: (a) 12 Beam pattern formed with ULA. (b) Circled star topology of the scenario

Overall with our study we conclude from the literature review that high gain adaptive antennas are best suitable to compensate to the high path loss and other blockages incurred in a mmWave indoor environment. In addition, higher frequency/spatial reuse can also be achieved per indoor environment thus allowing a very high throughput network in mmWaves [3]. This was necessary in order to get an idea of the number of probable beams in the LOS and NLOS regions to ensure maximum coverage of the nodes which then forms a basis for Beam Allocation to users. We estimate that generating around eight-twelve beams with two-three different beamwidths would be suitable for our scenario. The key factor counted on to decide this is the cell radius. Nodes which fall under non coverage area is another part which would be looked at later.

**C2: Interference Characterization and Graphical Procedures:** In this section we formulate the resource allocation for the considered indoor IoT network in terms of a graph coloring problem. The resources viewed here are the **Beams and Frequencies** respectively. We characterize the possible **Intra and Inter cell Interferences encountered in the cluster** and reflect on a single cell for study and examine the possible Intra-cell interferences and allocating resources within a single cell at first. Inter-cell Interferences are viewed at a later stage and forms the extended part of this research for future. The problem of interference arises when multiple nodes using the same frequency resources which are in close proximity attempt to convey messages about a sensed phenomenon (uplink transmission) at the same time. The cell uses a finite set of frequencies which are available to users .We observe several possible interferences and resource sharing problems within the cell as shown in Fig(2) (i) Beam Interference which occurs due to overlapping of beams (ii) Interference between nodes which fall in the common coverage area of two overlapping adjacent beams (iii) Interference between nodes in close proximity to each other in the same beam (iv) the problem of allocating resources to user/node which has the possibility to sit at the edge of a beam or two beams, quiet far from the base station/coordinating node. Having examined the interference aspects in the cell, our next step is to construct this interference in the form a graph called Interference Graph.

**Interference Graph Construction and Coloring**: Graph G=(V,E) is formed given a collection of vertex set$\{V_i\}$.The set of Edges E is constructed as the union of those pairs $\{V_k,V_l)$ of vertices that correspond to nodes/vertices $V_k$ and $V_l$ that would interfere with each other. Graph coloring is then adopted with the basic Principle: Given a Graph G= (V, E), color the node of the graph such that no two adjacent nodes have the same color. The smallest number of colors with this property is called chromatic or coloring number and is denoted by X(G) [4].

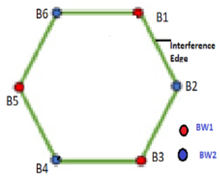



Fig:3: Cyclic Graph

As a first step we look at the beam overlapping which is a very common outcome of a multibeam environment. The graph at left, a cyclic graph shows the generation of six beams to cover the users. The **Vertices** represent the **Beams** and the Edges represent the **overlapping of two adjacent beams (Interfering)** which can also be seen in Fig(2). Two Colors are used to color the graph which is quite simple to solve based on the graph coloring principle. The two colors represent the two different beam widths to cover users in the environment. The same graph can be extended to twelve vertices to represent beams which would still use two colors following the graph coloring principle.

**Future work**: The next step is to characterize similar interference graphs in accordance with the interferences explained in C2 and to colour them with minimum colors by adopting suitable coloring algorithms which also involves solving the coloring problem under different constraints. The graphs are then analyzed to choose the optimal beam and frequency resources which can be allocated to an interfering user. Intra-cell interferences will also be characterized and similar graph methodology will be followed to find the optimal resource allocation

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**References:**

1. S. Talwar, D. Choudhury, K. Dimou, E. Aryafar, B. Bangerter and K. Stewart, "Enabling technologies and architectures for 5G wireless," 2014 IEEE MTT-S International Microwave Symposium (IMS2014), Tampa, FL, 2014, pp. 1-4
2. Hemadeh, Ibrahim A. et al. “Millimeter-Wave Communications: Physical Channel Models, Design Considerations, Antenna Constructions, and Link-Budget.” *IEEE Communications Surveys & Tutorials* 20 (2018): 870-913.
3. Rebato, M., Mezzavilla, M., Rangan, S., & Zorzi, M. (2016). “The Potential of Resource Sharing in 5G Millimeter-Wave Bands”. CoRR, abs/1602.07732.
4. A. H. Maaly, C. Andrew, “A Review of Interference Reduction in Wireless Networks Using Graph Coloring Methods”, International journal on applications of graph theory in wireless ad hoc networks and sensor networks (GRAPH-HOC) Vol 3, No. 1, pp. 58-67, March 2011.
5. T. Nieberg and J. Hurink, "Wireless communication graphs," Proceedings of the 2004 Intelligent Sensors, Sensor Networks and Information Processing Conference, 2004., Melbourne, Vic., Australia, 2004, pp. 367-372.
6. S. Gimenez et al., "Performance of hybrid beamforming for mmW multi-antenna systems in dense urban scenarios," 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Valencia, 2016, pp. 1-6.