A Project Report

on

DETECTING POOR TELECOM CELLULAR CONNECTIVITY USING DEVICE SIGNAL STRENGTH

Submitted By

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CONTENTS

INTRODUCTION

Next-generation heterogeneous cellular network (HCN) expects more and more deployment of the base stations and spectrum to achieve data rate in gigabits per second with seamless connectivity. At this stage, the demand from market is such that 5g should support much more system capacity than the 4G, which is already close to the Shannon Limit in point to point communication. Better connectivity, spectrum deficiency, and growing operational cost and capital cost are the critical challenges for the service providers. Presently, most of the wireless standards operate at the licensed ultra-high-frequency (UHF) bands. But these existing cellular bands (i.e., below 3 GHz bands) are not sufficient to give a better QoS. These challenges encourage both telecom industries and academia to search new paradigm for efficient utilization of radio spectrum, other possible frequency bands to enhance the network capacity and to rebuild the existing physical layer communication techniques in the best possible ways for the evolution of the 5G wireless networks.

For 5G, it is becoming challenging to find free bands for new networks/services to improve the QoS. Obvious ways to boost the peak data rates are extending the bandwidth of the system or search for a new radio spectrum. The available large underutilized radio resources in millimeter wave (mmWave) have the potential to solve limited radio resource issues of the existing cellular bands. There are recent breakthroughs that make the mmWave viable for cellular communications, and the cellular network infrastructure should be expanded accordingly.

Due to the dramatic growth in mobile data traffic, Multiple Radio Access Technologies (Multi-RAT) heterogeneous Networks (HetNets) have been proposed as a promising solution to cope with the high traffic demand in mobile networks. In a Multi-RAT heterogeneous network, we consider cells (base stations) of different radio access technology and associate the best network of the heterogeneous system to the user based on certain factors.

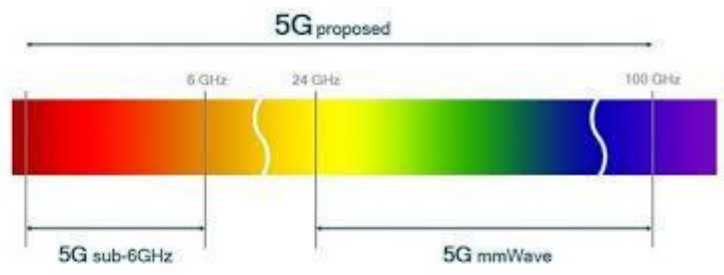
In this project, we propose a Multi-Rat selection scheme for user association using Matching game theory algorithm, where a mixed mmWave/UHF cellular network (abbreviated as MMUCN) is considered.

Study on mmWave band

Millimeter wave spectrum is the band of spectrum between 30 GHz to 300 GHz which is wedged between microwave and infrared waves. Current measurements/trials confirm that lightly exploited mmWaves have potential for solving the limited radio resource issue of the 5G and beyond cellular networks.

Although the mmWave bands extend all the way up 300 GHz, it is the bands from 24 GHz up to 100 GHz that are expected to be used for 5G. The mmWave bands up to 100 GHz are capable of supporting bandwidths up to 2 GHz, without the need to aggregate bands together for higher data throughput. This band is already used by several other wireless standards such as IEEE 802.11ad for local area networking, IEEE 802.15.3c for personal area networking, and IEEE 802.16.1 for fixed-point access links. The mmWave bands being made available for mobile networks will provide increased performance, better coverage, and a closer integration across multiple wireless technologies from 4G LTE to Wi-Fi, to sub-6GHz 5G, as well as extending to the higher frequency 5G mmWave bands.

However, the exploitation of mmWave bands for the cellular network also introduces new challenges because of inconsistent transmission behavior of the mmWave signals and several limitations such as low cost, small size (especially for mobile devices), spectral, and energy efficient system. Though it has a large underutilized spectrum, it has lot of drawbacks like susceptibility to blockages, high penetration losses and less coverage area due to its small wavelength.



The primary difference between the existing cellular networks and mmWave-based cellular network is susceptibility to blockages and the requirement of highly directional antennas at both transmitting and receiving node.

REVIEW OF LITERATURE

A research investigation (in 1956) on 30-300GHz frequency ranges showed that these frequency ranges can be used where high gain, huge bandwidth, and high directional antennas are required for the communication. Further, it was observed that high frequency signals do not cover large distances. Consequently, small wavelength signals cannot be capable of transmitting and receiving much energy in free space. Thus, to alleviate the strong signal attenuation that occurs at mmWave signals, directional antennas are necessary. An essential characteristic of mmWave-based communication system is its susceptibility to blockages. However, mmWaves experience substantially higher penetration losses when crossing by elements (such as ferroconcrete, tinted glass, and trees) due to the small wavelength and do not diffract well.

In the past few years, many experiments/trials campaigns and studies have been carried out by industries and academia to estimate the transmission characteristics of mmWave bands in different scenarios such as urban, rural, indoor, and outdoor. These measurements and trials on mmWaves reveal some useful insights related to the mmWave channel characteristics for cellular networks. They are:

• Transmission properties of the line of sight (LOS) and non-line concerning sight (NLOS) links are quite different.

• As compared to existing cellular band mmWaves experience higher attenuation and sparse multipath scattering.

• Wall penetration losses are also very large for mmWave bands as compared to the traditional cellular bands.

• Dense deployment of base stations with the directional antenna is needed to mitigate the substantial signal attenuation that occurred at mmWave signals.

One of the major issues associated with the cellular network is interference management from the nearby cells utilizing the same time-frequency resources. In the context of the mmWave band, features like beamforming and sensitivity to blockages alter the statistics of the interference encountered at the receiver. Various claims are drawn in the earlier experiments/trials about the sensitivity of mmWave band to interference. Some research claims that mmWave bands are noise limited, whereas some reports have argued that mmWave systems are interference-limited.

According to a research study, the behavior of the mmWave network also depends on the critical network parameters, e.g., base station density, number of users, antenna gains, beamwidths, bandwidth of the system, blockage model, path loss exponents, etc. The researchers considered 73 GHz and 28 GHz, two carrier frequency bands for the analysis. They found that the 73 GHz system favors being noise-limited, whereas a more considerable impact from interference is reported in the 28 GHz band. Numerically, they proved that the influence of interference rises with a smaller bandwidth and broad beamwidth in the beamforming.

After studying the available literature carefully, it is hard to give a precise conclusion of whether mmWave cellular systems are noise-limited or interference-limited, although many works reported that mmWave-based networks could be LOS interference-limited with high density. In few works, authors reported that increasing density of mmWave base station decreases the distance of the serving base station and increases the probability that serving mmWave base stations being LOS base station resulting in improved performance of the networks.

Taking into consideration all these factors, a system model has to be designed to utilize mmWave for cellular systems.

For various simulation purposes, and modeling the mmWave network system, the band can be considered as either noise or interference limited using certain assumptions and parameters.

Matching Game theory: Recently, matching game has emerged as a promising technique for wireless resource allocation, and user association. It is a Nobel Prize winning framework that provides mathematically tractable solutions for the combinatorial problem of matching players in two distinct sets, depending on the individual information and preference of each player. Although matching game has been used widely in resource allocation for cellular networks, it is still amateur in the HetNets user association.

Many authors and researchers in literature have considered heterogeneity in transmit power and very few have considered heterogeneity in RATs.

There are three types of mappings in game theory: one-one, many-one, many-many. For user association with base stations, many-one can be considered, i.e. one user can be associated to at most one user whereas one base station can be associated with any number of users.

Matching game theory uses OPT-UA algorithm, i.e. a cost function to associate a user to the base station and utility functions to associate the base station to an optimal number of users. A quota for maximum number of users that can be associated to a base station is defined.

$$OPT - UA: \quad \max_{x} \sum_{m \in M} \sum_{i \in I} x_{im} R_{im} \tag{1}$$

s.t.

$$\sum_{m \in M} x_{im} \leq 1, \qquad \forall m, i \tag{2}$$

$$x_{im} = \{0,1\}, \qquad \forall m, i, \tag{3}$$

$$\sum_{i \in I} x_{im} \leq \hat{N}^{L}, \qquad \forall m \in \mathcal{M} \backslash \mathrm{B}, i, \tag{4}$$

$$\sum_{i \in I} x_{im} \leq \hat{N}_{m}^{W}, \qquad \forall m \in B, i, \tag{5}$$

where objective function in (1) aims to maximize the total system throughput as a summation of UEs downlink data rates. Constraint (2) ensures that each UE is associated to only one BS, constraint (3) ensures that the decision variable x_{im} is a binary decision variable, constraint (4) and (5) ensures that each BS will not exceed its quota.

where R_{im} is the downlink data rate, N^{L} is the quota for UHF and N_{m}^{W} is the quota for mmWave

MOTIVATION

It is proved that HetNets can be energy efficient with maximizing the user coverage and improved data rates for every user.
Underutilized mmWave band can be a viable solution for future 5G and beyond networks, if modeled considering all its limitations as a large band of 24-100GHz usable range is available for wireless communications.

However, deployment of only mmWave base stations throughout the area in a future scenario may not be completely efficient as mmWaves comes with various limitations and problems. When considering mmWaves, LOS and NLOS come into picture where the SINR and probabilities of both differ. Also, blockages, penetrations might play a role in signal attenuation for distant users.

In HetNets, UE association is considered a significant challenge that received researchers' attention. In recent studies, Multiple Radio Access Technologies (Multi-RAT) heterogeneous Networks (HetNets) have been proposed as a promising solution to cope with the high traffic demand in mobile networks. This network system consist of multiple Radio Access Technologies (RATs) deployed in a heterogeneous system manner. A user is associated with one of the RAT based on various functions or parameters that best suits the user's demand. Generally, the association is done using any user association methods that have been studied for wireless networks.

Matching game theory is one such promising user association method for wireless communications that has been emerging in recent days. It is a Nobel Prize winning framework that provides mathematically tractable solutions for the combinatorial problem of matching players in two distinct sets, depending on the individual information and preference of each player.

In future, if mmWave is deployed along with UHF bands as a multi RAT network, this would overcome most of the challenges that would occur if mmWave is deployed as a whole.

PROPOSED METHOD AND ALGORITHM

In this project, we consider a multi-RAT network comprising of MMUCN (mixed mmWave/UHF cellular network). A user is to be associated with one of these RATs. After studying literature and going through various researches, we decided to use Matching game theory method for user association. In matching game theory, the algorithm consists of two parts- a user sending a biding request to a base station, and the base station accepting the incoming biding requests until a certain quota is reached(for maximum throughput). In literature, utility functions have been used for associating a user to a base station. The user equipment sends a biding request to the base station with maximum utility function Ui, and the base station accepts the requests for maximum utility function Uii until a quota is reached. In this work, we decided to use cost function as the parameter to associate a user with the base station (first part of the algorithm) and downlink data rates as the parameter to associate the base station with the users.

The set of all base stations (BS) is denoted by $\mathscr{M} = \{1,2, \dots , m, \dots , M\}$, with cardinality M, where m = 1,2 refers to UHF base stations, m = 3, … , M implies mmWave base stations. A set of UEs are distributed in a certain area under the UHF and mmWave base stations coverage and are denoted by I = {1, 2, N} with cardinality N. Moreover a quota for each RAT base station is represented by the maximum number of UEs that can be associated with a base station, and it can help to achieve maximum throughput.

For all the users deployed in the certain area, cost functions are calculated w.r.t every base station for each user. The cost function is given by:

$$T_j = w_{cj}B_j + w_{dj}n_j + w_{sj}S_j$$

where $j \in$ {uhf, mmW} and channel parameter B_j is the offered BW by the network. n_j and S_j are the density of the BSs and the signal strength at the corresponding user, respectively. w_{cj}, w_{dj}, and w_{sj} are the weights for the corresponding parameters. The higher value of T_j corresponds to better service provider tier for a generic user. The available BW estimates the service of a particular tier. We have taken SINR/SNR as parameters for signal strength in this work.

SINR values are calculated as given:

$$SINR_j = \frac{P_j\ (R_j)^{-a}}{\sum_{i=1}^{n}\ P_j\ (D_i)^{-a}}$$

where $j \in$ {uhf, mmW}, P_j is the transmit power of base station, R_j is the distance between base station and mobile (user/user equipment), and D_i refers to interfering base stations.

For UHF, the value of a is 4 and for mmWave, the value is 2. From literature, it is known that mmWave is sometimes noise-limited and sometimes interference-limited.

Cost function is the sum of the some normalized form of each parameter. Therefore, sum of the weights is taken as 1. The weight of the parameters may be modified as per the user requirement. In this work, we considered the weights to be equal.

After the weighted cost function values are known, the user considers the base station with the best cost function of all the base stations (max value) and sends a biding request to the respective base station. Similarly, all the users consider the maximum T_j value from all the values available for them and send biding requests to those particular base stations. This constitutes the first part of the algorithm.

After receiving the biding requests from users, the downlink data rates associated with each user for the particular base station is calculated. So, each base station will have a set of downlink data rates of all the users who sent a biding request. The downlink data rates are calculated using:

$$C_j = B_j \left[\log_2(1 + SINR) \right]$$

where $j \in \{uhf, mmW\}$, B_j is the bandwidth offered by the RAT, SINR is the SINR corresponding to the biding user and particular base station.

The set of downlink data rates for each base station are prioritized and sorted in descending order. The point of this step is to associate with users with maximum downlink data rates to maximize the overall system throughput. Now, each base station accepts the biding requests from users from the prioritized set until the quota of maximum users it can associate with is reached (denoted as N^L for UHF and N_m^W for mmWave). If the quota is reached, the remaining users with biding requests are rejected by the base station, and the users removes that base station from their set and repeat the process from the start by sending a biding request to the base station with next best weighted cost function value other than the earlier rejected base station.

This is the overall method for user association.

ALGORITHM

Initialization: M, I, N
Cost computation:
For Every UE_i construct $>_i$ using T_j
Find stable matching:
For each unassociated UE:
    Find m= arg max[$T_j(m)$]
    Send a biding request $b_{i,m} = 1$ to BS m.
For all BS m:
    Update $X_m^{req} \leftarrow \{ i: b_{i,m} = 1, i \in I \}$
    Construct $>_m$ based on $D_m(i)$
    repeat
        Accept i = arg max[$D_m(i)$]
        Update X_m
    until $X_m = N^L$, $m \in \{1,2\}$
      or $X_m = N_m^W$ $m \in \{3,4,\ldots.M\}$
    Update X_m^{rej}
    Remove UHF or mmWave BS $m \in >_i$, $\forall i \in X_m^{rej}$
end

Terminology

M – Number of base stations with cardinality M

I – Number of users with cardinality N

$>_i$ – Preference relation function

$b_{i\to m}$ – Biding request for association

Tj(m) – Cost function corresponding to BS m for each user

X_m^{req} – List of incoming biding requests from users for BS m

$D_m(i)$ – Downlink data rates corresponding to BS m for each user

X_m – List of connected/associated users to BS m

X_m^{rej} – List of rejected users for BS m

N^L - Maximum number of users a UHF base station can associate with

N_m^W - Maximum number of users a mmW base station can associate with

RESULTS AND DISCUSSIONS

Since our work is based on theoretical simulation, we've made some assumptions and taken the parameter values based on literature survey and various research studies.

The values considered are as follows:

Transmit power of UHF BS = 10W

Transmit power of mmWave BS = 1W

Noise power of UHF BS = -110dB

Noise power of mmWave BS = -70dB

Density of UHF BS = 10^{-6}

Density of mmWave BS = 10^{-4}For simulation, we have taken the number of users as 20 and the number of base stations as 4, where 2 are UHF and 2 are mmWave.

We assumed the mmWave base station to be LOS noise-limited system. So, the NLOS SINR has been ignored.

The distances between user and base stations are generated randomly.

Following are the results after simulation for the given parameters:

Distances between users and base stations:

Variables - R

R

20x4 double

	1	2	3	4	5	6	7	8
1	297.1494	590.9311	584.7126	186.9443				
2	433.2879	411.7519	383.1101	610.2593				
3	192.6975	229.4711	92.2580	658.4823				
4	455.4308	340.8296	451.1287	385.8541				
5	456.6449	385.2813	507.5222	370.5218				
6	695.6562	160.8869	83.0008	85.6913				
7	53.8780	289.1602	319.3773	262.4132				
8	536.8182	443.2485	542.6665	653.6690				
9	681.1912	142.4996	105.8232	490.4238				
10	74.7358	372.5290	375.9375	604.1865				
11	344.5488	281.4849	473.2875	521.4680				
12	368.8362	249.9217	113.4981	414.4035				
13	190.8803	40.6733	530.9040	177.5219				
14	315.2576	484.5793	257.8675	518.0747				
15	282.3482	481.5569	495.7927	315.1907				
16	23.5086	238.2919	302.7736	196.4866				
17	145.9671	576.9876	306.6458	622.5620				
18	279.9163	540.6889	283.7861	567.8747				
19	531.0032	270.4029	159.0531	555.3810				
20	665.0197	236.0201	473.1724	312.6650				
21								
22								
23								

Range: 20-500m

Downlink Data Rates:

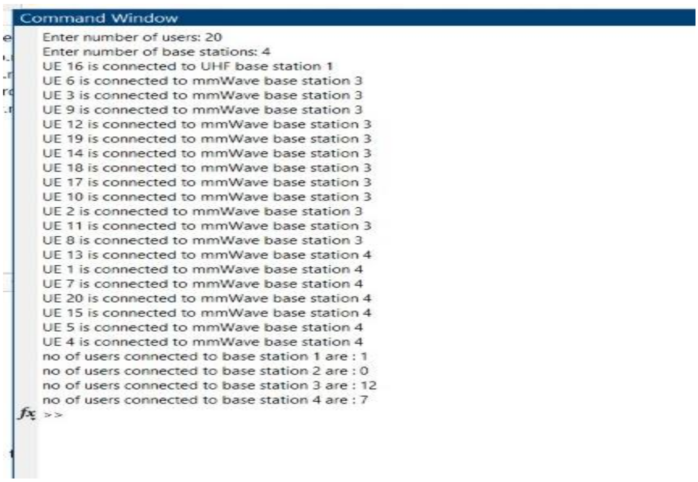
Variables - dldr

dldr

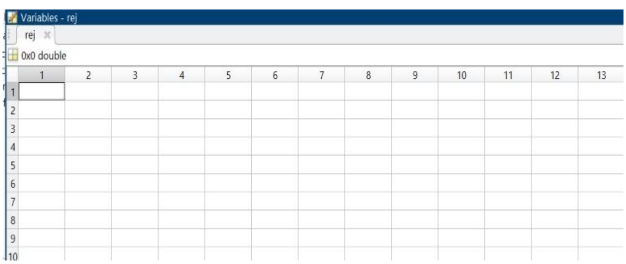
20x4 double

	1	2	3	4	5
1	3.3938e+08	2.6003e+08	1.4836e+10	1.8126e+10	
2	2.9584e+08	3.0173e+08	1.6056e+10	1.4713e+10	
3	3.8936e+08	3.6921e+08	2.0164e+10	1.4493e+10	
4	2.9009e+08	3.2355e+08	1.5585e+10	1.6035e+10	
5	2.8979e+08	3.0940e+08	1.5245e+10	1.6152e+10	
6	2.4121e+08	4.1019e+08	2.0469e+10	2.0377e+10	
7	5.3645e+08	3.4252e+08	1.6581e+10	1.7148e+10	
8	2.7112e+08	2.9322e+08	1.5051e+10	1.4515e+10	
9	2.4363e+08	4.2419e+08	1.9768e+10	1.5344e+10	
10	4.9868e+08	3.1328e+08	1.6111e+10	1.4742e+10	
11	3.2229e+08	3.4563e+08	1.5446e+10	1.5166e+10	
12	3.1443e+08	3.5935e+08	1.9566e+10	1.5830e+10	
13	3.9046e+08	5.6890e+08	1.5115e+10	1.8276e+10	
14	3.3255e+08	2.8293e+08	1.7198e+10	1.5185e+10	
15	3.4527e+08	2.8365e+08	1.5312e+10	1.6619e+10	
16	6.3217e+08	3.6485e+08	1.6735e+10	1.7983e+10	
17	4.2142e+08	2.6279e+08	1.6698e+10	1.4655e+10	
18	3.4627e+08	2.7029e+08	1.6922e+10	1.4920e+10	
19	2.7237e+08	3.5026e+08	1.8593e+10	1.4985e+10	
20	2.4640e+08	3.6596e+08	1.5447e+10	1.6642e+10	
21					
22					

Final output after associating the users to each base station:



Rejected list of users:



SUMMARY AND CONCLUSIONS

Our goal is to find a suitable method to associate users in a multi RAT network to one of the RATs using a selected algorithm. We've chosen matching game theory which is a famous and efficient algorithm that has been emerging in recent years, and used cost and utility functions for two-sided stable matching. By using parameters like SINR, Downlink data rates and cost functions, we were able to devise a strategy and algorithm. MATLAB is used for simulating the proposed algorithm. Our algorithm worked as expected for the given parameter values and the final output was that users were associated with certain base stations until the quota of the base station is reached. The indices of rejected users were stored in an array to be displayed as well. Further, this work can be extended by finding Outage probabilities and also considering an interference limited network to obtain more results. The proposed strategy gives a two-sided stable matching as the Matching game theory is used to get such stable results.

APPENDIX

Cost function: $T_j = w_{cj}B_j + w_{dj}n_j + w_{sj}S_j$

where j ϵ {uhf,mmW} and channel parameter B_j is the offered BW by the network. n_j and S_j are the density of the BSs and the signal strength at the corresponding user, respectively. w_{cj}, w_{dj}, and w_{sj} are the weights for the corresponding parameters.

SINR: $$SINR_j = \frac{P_j\ (R_j)^{-a}}{\sum_{i=1}^{n}\ P_j\ (D_i)^{-a}}$$

where j ϵ {uhf, mmW}, P_j is the transmit power of base station, R_j is the distance between base station and mobile(user/user equipment), and D_i refers to interfering base stations.
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Downlink data rates: $C_j = B_j\ [\ \log_2(\ 1 + SINR\ )\ ]$

where j ϵ {uhf, mmW}, B_j is the bandwidth offered by the RAT, SINR is the SINR corresponding to the biding user and particular base station.

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