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Precision Indoor Positioning System for 5G

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Abstract:

5G refers to the fifth generation of mobile networks, and this standard is based on operating in a high-frequency band between 30 GHz and 300 GHz of the wireless spectrum. This is also known as the millimeter wave spectrum. The millimeter waves can transfer a huge amount of data at very high speeds, offering greater capacity.

In order to meet the required capacity, 5G systems are required to have high bandwidth. However, with such high-frequency waves, there are many associated problems. One such problem is knowing the exact location of a device to communicate with it. As the beam width is small for mm waves, point-to-point communication is required, and hence exact location is a necessary requirement. This paper focuses on challenges encountered with 5G, potential solutions for developing an efficient indoor positioning system, as well as describes a thoroughtesting framework.

Keywords **—Wireless networks, 5G, Communication systems**

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I. INTRODUCTION

Mobile communication is rapidly growing, andthis has resulted in a need for better network capacity, speed, and experience. Furthermore, statisticsfrom [1] show that 80% of 4G mobile services takeplace indoors. With 5G, this figure will increase toaround 85%. Hence, the quality of indoor networkswillbethecorecompetitiveedgeofmobileoperators in the era of 5G. This paper will addressquestionssuchas:

1) **Whatis5G,andwhyisitneeded?**
2) **How will an indoor mobile network for 5Gbebuilt?**
3) **What are the various problems that wouldbe encountered when developing a preciseindoorpositioningsystemfor5G?**
4) **Whatarethesolutionsforthesame?**

The paper also describes the architecture and thedesignforan'AutonomousFlyingdrone'whichwouldactasamobilephonetotestthe5Gsystem.

II. 5G TECHNOLOGY

5Greferstothefifthgenerationofwirelesstechnology.Itisoneofthefastestandmostrobust

technologies the world has ever seen. This impliesthattherewouldbeamassiveeffectonhowwe live.Itwouldresultinquickerdownloadsandbetter connectivity. These benefits of 5G will makebusinesses thrive and will also provide consumerswithaccesstoinformationveryquickly.

III. NEEDFOR5G

Undoubtedly4Ghasadvantagesover3Ginterms ofprovidinghigherspeedandincreasedsecurityoverdataconnectionson3G.However,ithascertaindisadvantagesaswell.Thesignificantdrawbacksareasf ollows:

1) Lowglobalpenetrationrates
2) Highcostsindevelopingmarkets
3) Significantinfrastructureinvestmentisneed edtodeploy4G
4) Poorurbanconnectivityandslowerreal-worldspeeds
5) 4Gconnectionsarepowerinefficient
6) Highlatency

IV. INDOOR5G

A. Requirementsfor5GIndoorDeployment

Indoor network deployment requires that for siteaccess,thereneedstobeinteractionand coordination with mobile operators. It requires complexinstallation and also expensive on-site maintenance.In 5G, dense deployment is a common feature. Thiswill result in a drastic increase in the amount ofnetworkequipment.

Thingstobeaddressed:

- Monitoring of a massive number of head ends in a indoor network in real time.
- Visual realization of O&M, fault diagnostics,self-healing.
- Assigningofnetworkresourcesaswellasauto matically optimizing it in response to userdensityandchannelconditions.

Itisextremelyimportantforoperatorstoaddressthechal lengesofmeetingthedemandfordenser connections, proliferative mobile data traffic and accuracy of positioning while achieving a smooth transition to 5G.

B. Specifications of Indoor 5G Network

ITU Report on IMT-2020 Minimum Require-ments specified the following criteria that 5G must satisfy (4).

Fig. 1Table 1: ITU Report on IMT-2020

Metric	Requirement	Comments
Peak Data Rate	DL: **20 Gbps** UL: 10 Gbps	Single eMBB mobile in ideal scenarios assuming all resources utilized
Peak Spectral Efficiency	DL: **30 bps/Hz** (assuming 8 streams) UL: 15 bps/Hz (assuming 4 streams)	Single eMBB mobile in ideal scenarios assuming all resources utilized
User Experienced Data Rate	DL: 100 Mbps UL: 50 Mbps	5% CDF of the eMBB user throughput
Area Traffic Capacity	Indoor hotspot DL: 10 Mbps/m^2	eMBB
User plane latency	eMBB: 4ms URLLC: **1ms**	Single user for small IP packets, for both DL and UL (eMBB and URLLC)
Control plane latency	20ms (encouraged to consider **10ms**)	Transition from Idle to Active (eMBB and URLLC)
Connection Density	1M devices per km^2	For mMTC
Reliability	99.9999% success prob.	32 L2 bytes within 1ms at cell edge
Bandwidth	>100 MHz; up to **1 GHz in > 6 GHz**	Carrier aggregation allowed

Precise Positioning is recognized as an important application for 5G cellular networks. This is due to the large number of use cases such as:

1) Remote operation
2) Emergency call-outs
3) Industry automation

Radio based positioning has always been a challenging task in urban environments, where tall buildings block and reflect the signal between the user equipment and the transmission point.

C. Challenges for 5G

Higher frequency bands result in greater link losses as well as weaker indoor coverage. For example, outdoor signals on the C band will be subject to an 8 to 13 dB link loss when penetrating through one concrete wall. The signals on the higher mmWave band will experience difficulty in penetrating through a wall as the link loss exceeds 60 dB (3). It is definitely a great challenge for outdoor 5G macro signals to cover indoor areas, and a dedicated network will be required for indoor environments. 5G dedicated network for indoor settings must be built in parallel with outdoor 5G network to meet the huge bandwidth demand while at the same time ensuring good 5G services.

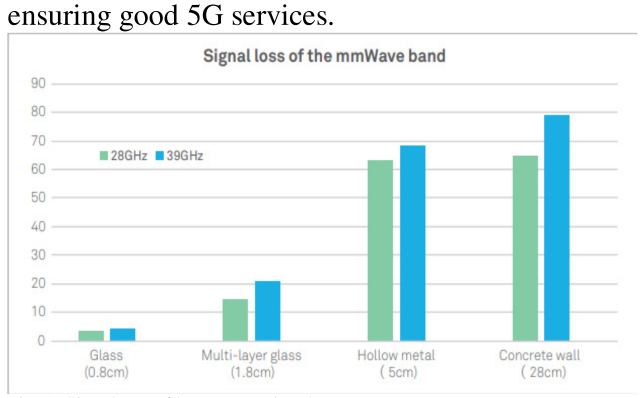

Fig. 1 SignalLossofthemmWaveband

V. NEED FOREFFICIENT INDOOR POSITIONINGSYSTEM

Foroutdoorsettings,GPS(GlobalPositioningSy stem) plays a dominant role in localization. How-ever,itdoesnotworkwellinindoorsettings.Thisis because the signals emitted by GPS are weak andare difficult to penetrate most building materials.Therefore, GPS does not suit well in indoor environments. Thus there is a need for efficient indoorpositioning systems and various indoor localizationtechnologies have been developed to address this.However,duetothecomplexityofindoorenvironments,therearemanychallengesassociatedwitthe development of indoor localization techniquessuchas:

1) NLOS(nonelineofsight)
2) Multipatheffect
3) Noiseinterference

These issues result primarily because of obstacles,suchaswalls,equipment,etc,duringthepropagation of electromagnetic waves. For example, themovement of people causes changes in the physicalconditions of the environment, which in turn mightaffectthebehaviorofwirelessradiopropagation.

VI. WORKING PRINCIPLE OF INDOOR POSITIONING SYSTEM

An indoor localization system is a system that can determine the position of any person or anything in a physical space continuously and in real time.

Basic Architecture of the indoor Positioning system:

1) Every reference node sends a signal to thedevice under test. This signal might containthelocationofthereferencenodes.
2) Upon receiving this signal, the mobile under-test issues a response signal back to the referencenodes.

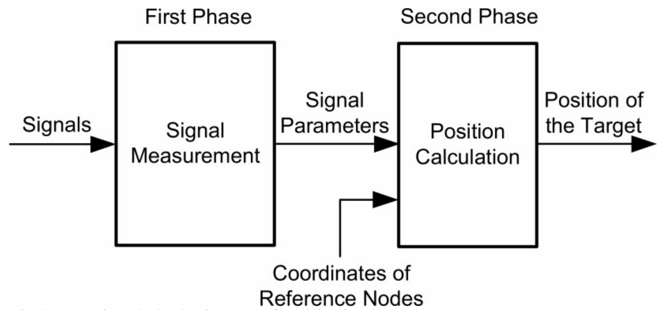

Fig.3.FunctionalBlockDiagramofPositioningSystem

3) During this process, some of the signal properties, such as arrival time, direction, signalstrength, etc., are captured by the referencenodes, which are then used for calculating theexactlocationofthemobileundertest.
4) This information can then be sent to the basestationsoastodirectittopointtowardthe mobile phone for efficient communicationbetweenthem.
5) Tosummarize,wemeasuresome position-related signalparameterscorrespondingtowireless communications between the targetand the sensor; and then the physical positionofthetargetiscalculatedbasedonthesesignalparameters.

   The next few sections (VII To X) go oversome of the popular indoor positioning systemspresenttoday.

VII. INFRARED(IR) BASEDPOSITION SYSTEMS

The major advantage of IR is its wide availability as many devices are equipped with IR sources, such as mobile phones, TV, etc. IR-based systems do not need costly installation and maintenance. However, it can not be applied to some kinds of indoor scenarios in which the environment is pretty complex because of its requirement of line-of- sight and its inability to penetrate opaque obstacles. Also, distortion or interference is produced by other neighboring IR devices.

VIII. RADIO FREQUENCY (RF) BASED POSITION DETECTION SYSTEMS

The systems designed based on RF can cover a larger distance since it uses electromagnetic transmission, which can penetrate even opaque objects such as people and walls. Also, RF systems are known to uniquely identify people or objects in the system. In RF-based systems, techniques such as Triangulation and fingerprint are widely used. Based on this technology, Radio Frequency Identification (RFID), Wireless Local Area Network (WLAN), Bluetooth, wireless sensor networks, and Ultra Wide Band (UWB) are created. In addition, RF-based technologies are classified into narrow band-based technologies (RFID, Bluetooth, and WLAN) and wide-band based technologies (UWB). Amongst these, UWB technology is the most accurate and fault-tolerant system that has widespread usage in indoor localization.

IX. ULTRASOUND BASEDPOSITION DETECTIONSYSTEMS

Ultrasound Based Position detection Systems are cheap compared to other technologies. However, when considering the precision, it is lower than IR-based systems due to the influence of reflection. Furthermore, these systems are always associated with RF technology in order to fulfill the synchronization requirement, which potentially increases the cost of the entire system.

X. GPS REPEATERSBASED POSITION DETECTION SYSTEMS

This technique consists of collecting GPS signals from the best possible environment (typically from an outdoor antenna), then forwarding them indoors in a sequential switching mode without any further treatment other than amplification. In order to overcome interference problems, signal retransmission is carried out using sequential switching between repeaters. Each repeater transmits signals over a specific period while the others are switched off. Signal-switching from one repeater to the other forms an offset in the phase of the signal received at the indoor receiver. The phase offset of the received code, also called code phase jump, corresponds to the difference between the distances separating the GPS receiver from two successive transmitting repeaters. These phase offsets are detected and measured at the output of the code loop discriminator. As in GPS positioning, which needs four satellites to achieve 3D Positioning, four repeaters are necessary to have three independent phase offsets. Using these offset values, we can obtain the position of the indoor receiver object in 3D using some appropriate navigational algorithm (9).

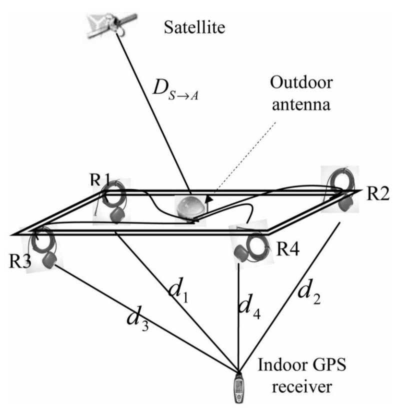

Fig. 4. Indoor GPS Positioning System

XI. PROPOSED SOLUTION - 5G + 4G

All these systems designed for a precise location can provide around 95 percent efficiency, even after incorporating mechanisms such as machine learning.

Since 5G has harmful biological impacts, if the beam direction is even slightly off, it would be detrimental to human’s health. My solution is based on minimizing the hazards caused to human-beings. When the reading from the sensors is below a threshold value, where the threshold would serve as the confidence level of accurate position, we will use 5G to communicate till the local tower and 4G from the local tower till the user. If the sensor values are above the threshold, it implies that accurate measurements have been obtained and 5G is used end-end. This way, the harmful biological impacts would be reduced and also has lower latency thana traditional 4G or 3G service.

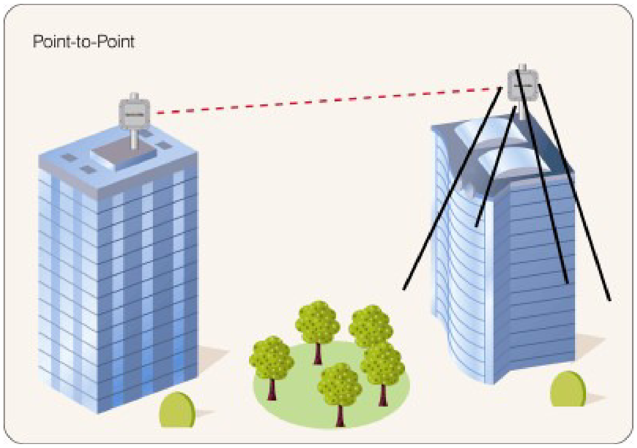

Fig. 5. 5G + 4G Architecture

Apart from that, since this solution uses restricted 4G, it would overcome some of the disadvantages of 4G such as interference, increased latency, reduced spectrum efficiency etc. As we are using 4G for a small coverage area, we can increase the capacity and thus serve more users.

XII. TESTING USINGDRONES

Compared to outdoor positioning, indoor positioning faces more problems:

1. The coverage of indoor positioning signal in wide area: The wide coverage of positioning signals in indoor positioning environment is the basic condition in wide area. Technologies like Wi-Fi, Zigbee, RFID, UWB, Bluetooth, and Pseudolite can offer high-accuracy indoor positioning signals in local areas, but they fail when it comes to wide areas for the limited coverage range. Ideally, for the best indoor position system, the widely covered cellular network is the best. However, the signals of current 2G/3G/4G cellular networks cannot meet the requirements for wide area high-accuracy indoor positioning because of the limitation of signal systems and network optimization. Considering the profit margin, the operators will not pay the construction and maintenance bill for a single network which provides only positioning service. Hence it be- comes important to design a system which can carry a high-accuracy and high-gain positioning signals without affecting existing services of cellular networks.

2. High-accuracy ranging and positioning in terrestrial channel: Compared to the satellite channel of Global Navigation Satellite System(GNSS), indoor positioning faces the terrestrial channel, which is more complex. The key information for positioning is the high-accuracy ranging information based on time delay and Received Signal Strength (RSS). The phenomenon of multipath and fast fading is much more serious in the terrestrial channel, especially in urban indoor environments. Signal varies by the effect of multipath and fast fading, which in turn increases the ranging error. When the channel condition is severe, the ranging error will rise up to tens of meters to worsen the indoor positioning accuracy. Another problem caused by terrestrial channels is Non-Line-Of-Sight (NLOS), which adversely affects the positioning result accuracy. In a cellular network, the error caused by NLOS can be more than 100m. Thus the terrestrial channel brings a great challenge for precise indoor positioning.

The methods described above face a common problem known as Blind Spots. Blind spots are the places in which mobile phones are not accessible by the positioning system. For example, the mobile phone can be under a desk or covered by a wooden shelf. Even the corners of the room can sometimes be inaccessible by the positioning systems.

For accurately determining the precision of such positioning systems, we need a drone that can operate under predefined steps. Hence we can rigorously code in the test cases on the drone and check the system for worse possible cases. Also, the advantages of a drone over a manual test and 2D robots are not limited to altitude but also the angle of operation. A drone can help us get varied results for the worse condition possible.

These drones can also be programmed to work autonomously. Obstacle-avoiding drone is one of the implementations that I will be trying in this project. This autonomous operation of the drone will help us find the hidden test cases that we could possibly miss out.

XIII. DESIGN CONSIDERATIONSFOR DRONE

The sole purpose of simulating the testing using a drone is to address the test cases which are not obvious or hidden. Thus, a primary requirement of the drone is to work autonomously using some algorithm. The design that I am working on here is an obstacle avoiding drone which will act like a mobile.

Possible different test conditions (parameters):

1. Speed Test: This autonomous drone can indeed undergo a drastic change in its speed with respect to time. This will perhaps help us evaluate the fluctuations in position estimation.

2. Altitude Test: Similarly, we can also test the system by drastically changing the altitude of the drone while autonomously flying in a room.

3. Position Test: The position of the drone with respect to the reference nodes can be changed with every different position, and hence we can get an overall idea of the precision with respect to the position of the reference nodes.

4. Angle Test: The pitch and Yaw axis can be manipulated, and different angular motions can be attained (10).

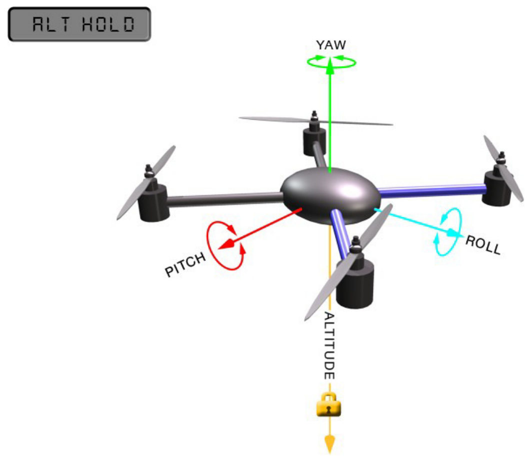

Fig. 6. Drone Movements

5. Stress Test: All the above mentioned test cases can be combined together to test the system in extreme conditions.

Along with its autonomous operation the drone can also be controlled wirelessly using WiFi (IOT). Another mode of operation is to program the drone

with custom test cases. All these modes of operation will enable us to control the drone and operate it under different conditions.

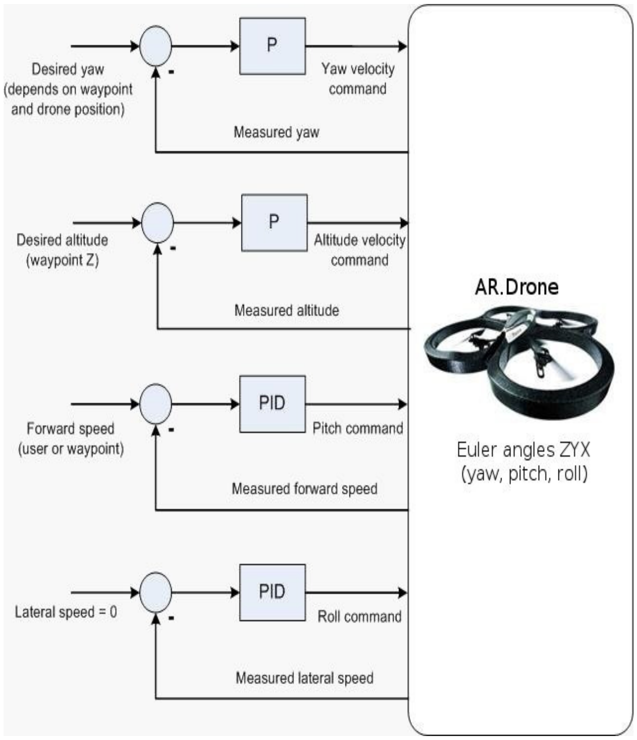

Fig. 6. DroneFunctionalBlockDiagram

A.PseudoCode

Start:
wait:StartSignal
if(obstaclefront),
side check right
else
moveforwardwhile(
!obstaclefront) _

movestop_
if(firedetected),fire

reverse:movebackwardif(ob
stacleleft),side check right
if(obstacleright),
side check left

movestop_
jumpreverse
side check right:
movestop
if(obstacleright),side check left

moveright
Delay1sec
_
movestop
if(!obstaclefront),forward
if(obstacle right),
side check right

side check left:
movestop
if(obstacleleft), reverse
moveleft
Delay1sec

movestop
if(!obstaclefront),
forward _
if(obstacleleft),
side check left
fire:
movestop
if(firedetected),
fire

XIV. CONCLUSION

This paper describes the various challenges associatedwith5G andtheproblemsassociatedwhen developing a precise indoor positioning system. This paper proposes a solution of integrating5G-4G architecture that uses 5G as the base architecture under normal conditions and switches to 4Gunder conditions where precise measurements aresometimes not achieved (indoor). This also helpstackletheproblemofbiologicalimpactsof5Gt oa certain extent. The paper also details the need forusing drones to test the different indoor positioningsystemsandgoesoveritsdesignconside rations.

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