

Impact of 5G Technology on IoT Applications in Construction Project Management

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Abstract –

IoT based platforms are enhancing decision-making capabilities in many sectors. The impact of IoT in construction has not been significant because of the unstructured nature of the process and the project-based approach to construction. Further, the technology platforms available today do not support high data flow from distributed locations as required for construction. However, it is anticipated that the use of IoT in construction will increase significantly when standards such as 5G are implemented for widespread usage. The first objective of this paper is to identify the potential usage of IoT technology for various construction project processes based on the PMBOK framework for construction. Several works on the applications of IoT which have been published are reviewed, and a framework for construction domain is proposed. The second objective is to identify and discuss the barriers raised by connectivity issues within this framework and influence of 5G technology in overcoming this barrier is elaborated. A comparative quantitative analysis of sample processes is presented to show the potential advantage that 5G technology will bring over 4G with the help of an example.

Keywords –

IoT, 5G, Digital Construction, Wireless Technology, Connectivity in Construction

1 Introduction

IoT is one of the disruptive technologies in recent years which have brought groundbreaking improvement to commercial, consumer, industrial and infrastructure applications. IoT based platforms can gather data to make the decision-making process faster and more efficient. IoT has brought significant change in operations and decision making in several sectors such as manufacturing, healthcare, agriculture, energy, etc. Unlike construction, these sectors involve repetitive processes mostly in a closed working environment

which makes the adoption of this technology.

On the other hand, the construction sector is different as it involves complexities like unstructured processes, erratic work environment, and remote construction sites. Construction is also a highly fragmented as well as a multi-disciplinary industry. Therefore, the adoption of IoT in construction will require significant effort in ensuring appropriate changes at policy, technology and project implementation.

In construction, the technology succession planning has not been managed well. Woodhead suggests the construction industry needs to undergo a pivotal shift to digitized processes to make the project delivery process cost-effective. Companies that don't embrace this shift will not be able to ensure sustained business growth due to significant productivity losses [1].

The process of digitalization has brought with it an improvement in many domains including productivity, agility, innovation, consumer experience, quality, costs and revenue [2]. Even though there have been significant advancements in construction techniques, materials, automation of the worksite, scheduling techniques and collaborative platforms like BIM, concerns have been expressed on the resistance to adopting such technology in the construction sector.

The applications of IoT are vastly spread across all domains. Although other sectors are integrating it into their everyday process, the construction industry is lagging in adopting an IoT eco-system. A recent study by Burger identifies several areas for application of construction projects such as remote operation, supply replenishment, construction tools and equipment tracking, equipment servicing and repair, remote usage monitoring, augmented reality (AR), Building Information Modelling (BIM), predictive maintenance, progress monitoring, construction safety & quality monitoring [3].

Woodhead stated that construction companies which are using IoT for decision-making process are using it more as a point-based model for solutions to some of their problems and not developing an ecosystem for all-around integrated business decision support [1]. For

example, an IoT based early warning system was proposed by Ding et al. for safety management in an underground construction project in China [4]. Another application is of an IoT enabled BIM platform (MITBIMP) by Zhong at el. to achieve real-time visibility and traceability in prefabricated construction [5]. There are many such examples of specific applications of IoT in construction in the field of quality, safety, inventory management, etc.

In spite of proven advancement in IoT technology, there remain certain barriers in IoT implementation. These include connectivity issues, such as high latency, low speeds, and large connection density. There are also technological issues such as presently used ERP systems which lack tools for integration of IoT in their design.

Applications of IoT in construction today are scattered, and due to the remoteness of sites and work locations, there are connectivity barriers. Hence with these capabilities of IoT which can revolutionize construction, an IoT framework specific to construction appears to be the need of the hour. Further, the shortcomings due to connectivity standards to that framework should be addressed for smooth

implementation. Therefore, this paper attempts to:

1. Identify the potential usage of IoT technology for through a holistic framework which encompasses various processes of a construction project.
2. Identify and discuss the barriers raised by connectivity issues within this framework and the influence of 5G technology in overcoming these barriers.

This paper is broadly divided into three sections; the first section describes the potential applications of IoT platforms in construction management based on the established PMBOK framework. The second section proposes a layered structure of IoT ecosystem for construction and explains in detail about the various layers. The third section of this paper highlights the benefits that 5G standard of connectivity can bring to address the existing barriers and challenges in the implementation of IoT technology. This discussion will emanate from a general context of IoT technology but will move on to focus on the construction sector in particular. In the final section, the conclusions and future implications of this study are presented.

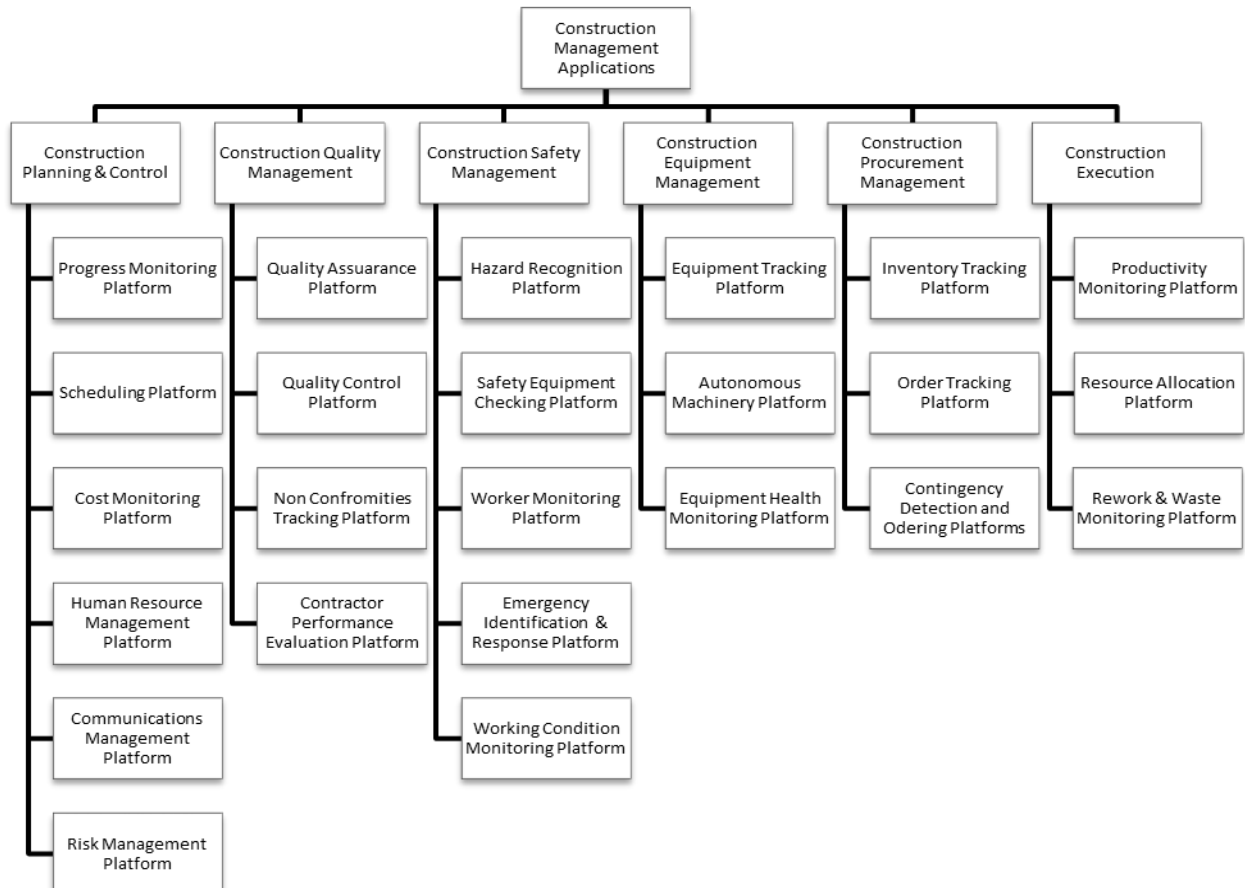


Figure 1. Applications of IoT platforms in construction phase of a project

2 Framework of IoT Application in Construction

For proposing a holistic framework for construction processes, this paper adopts the widely accepted PMI-PMBOK framework for project management. The PMBOK framework has been developed with the inputs from numerous project management professionals and covers all the essential processes required for construction under the following six categories [6].

1. Construction Planning & Control
2. Construction Quality Management
3. Construction Safety Management
4. Construction Equipment Management
5. Construction Procurement Management
6. Construction Execution

Figure 1 shows the few of the applications for which IoT platforms can be installed to facilitate these areas in the construction phase of the project. There can be many more applications depending on the characteristics of the project.

Each of these platforms can be embedded in a different type of data collecting devices. Example, a progress monitoring platform can be embedded in imaging devices, bar codes, RFID tags or even laser scanners. A study from MIT on construction safety by Bernal et al. demonstrated application of various sensors to monitor a worker's health, the worker's vest and jacket can be embedded with many sensors to monitor the working conditions [7]. Similarly, data can be obtained from installing sensors in worker's shoes, helmet, etc. These data can be stored in the company's database and can be accessed for monitoring by the

safety team; they can identify dangerous situations and can alert the worker, worker's team or site supervisor. A GPS based sensor can be used for tracking and collecting information on equipment.

2.1 Structure of an IoT Ecosystem

Figure 2 represents a proposed network outline for the flow of data for Integrated IoT applications on construction sites. A construction project can have n numbers of sites where execution is going on simultaneously. Within these sites, there can be m number of processes or activities going on. The integrated IoT system will capture data for all the departments ($m \times n$ data types); hence there should be a combined embedded system of sensors, actuators and other IoT things fitted for each processing environment. The sensors for the respective departments capture the needed information, and this data can be accessed by the concerned department or the management staff in the project office to facilitate decision making.

Figure 3 illustrates a proposed structure of IoT Ecosystem for decision making in construction management. The Integrated IoT in projects can be enabled by five layers which connect with one and another sequentially to form IoT platforms.

2.1.1 Physical Layer or Sensing Layer

It is the bottom-most layer which consists of the devices that capture or senses the information. This layer is also called the perception layer as it perceives the data from the environment [8]. These devices consist of several sensors, actuators, RFIDs, mobile devices, etc. which forms a network of things.

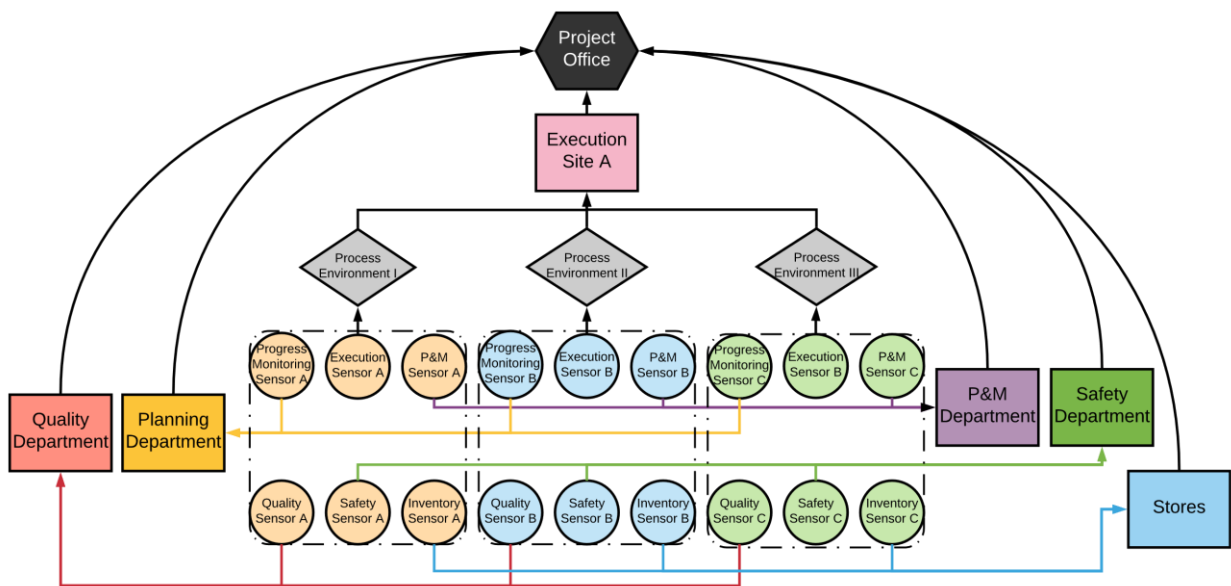


Figure 2. A proposed network outline for data flow for integrated IoT application on construction sites

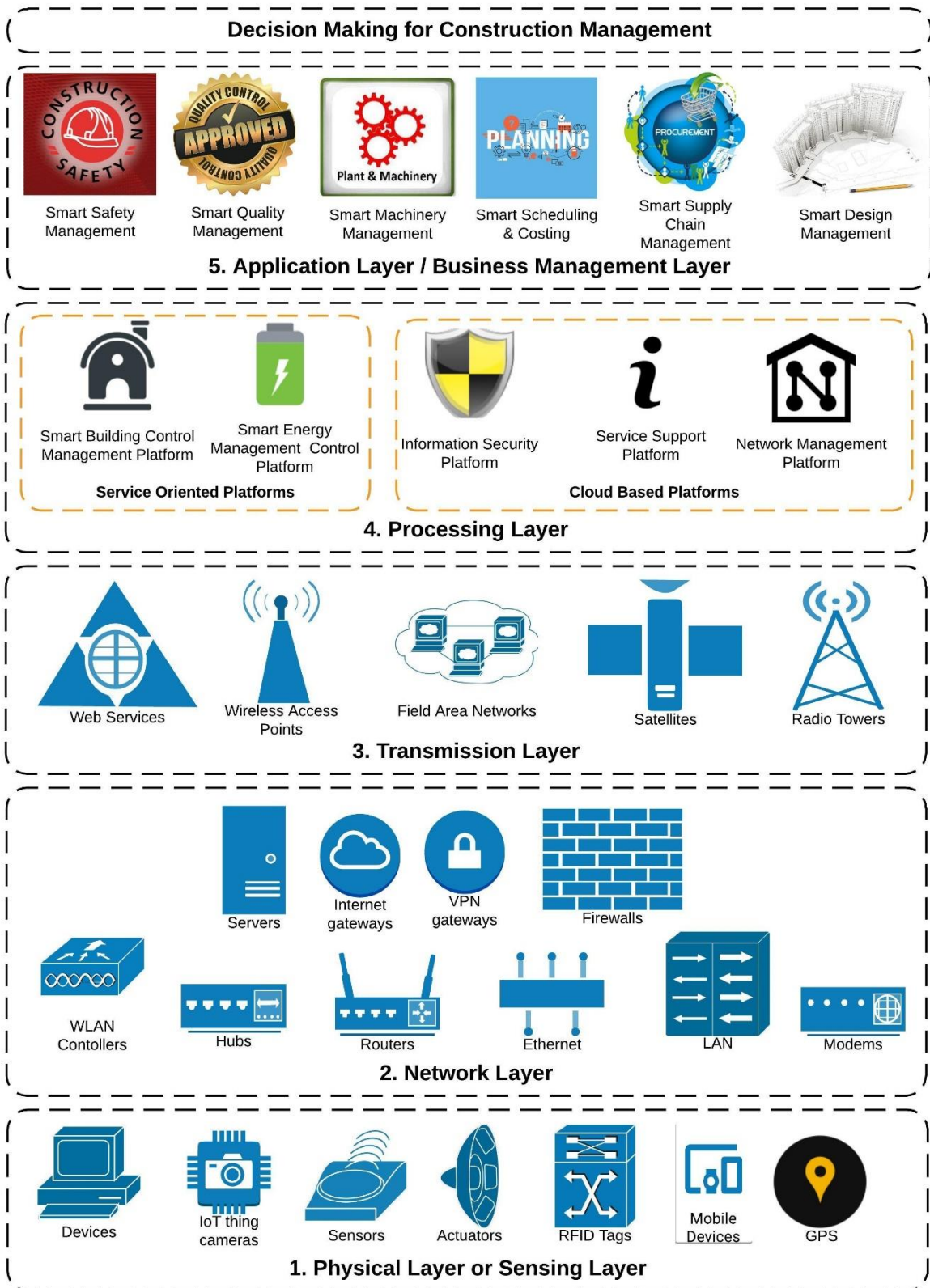


Figure 3. A proposed structure of IoT ecosystem for construction project management decision making

These can be of two types, static and mobile. In a construction project environment, these can be placed anywhere in the site, inside offices, integrated with the machinery, in the hands of site engineer or elsewhere from where it can capture valuable data. These things are connected directly or indirectly to the IoT network after signal conversion and processing. These devices form nodes of the network. In the sensing layer, the nodes are subject to different constraints such as energy limitation, the reliability of wireless medium, security, and privacy [9].

2.1.2 Network Layer

The network layer is one of the two sublayers of the connectivity layer which comprises the local networks of routers, hubs, LAN controllers, servers and other necessary network forming devices. This layer acts as the interface between nodes and the internet. The nodes or things are connected to the gateways present in this layer. The VPN gateway serves as a jurisdiction to the nodes under it and assigns a local address to them in a local area network. IPv6 is commonly adopted for addressing IoT nodes. From that point data flows through a proxy server if internet access is required and then to a web socket in the next layer. When these nodes are needed to interact with each other, or they are transmitting data, they send it to destination nodes. The data first must be transferred to the local network and then if the intended destination is outside the local network, then it is sent through internet gateways.

2.1.3 Transmission Layer

The transmission layer is the second sub-layer of the connectivity layer. This layer acts as interphase between the network and cloud platforms when the data is stored and analyzed. It focuses on end-to-end communication and provides features including reliability, congestion avoidance, and guaranteeing that packets will be delivered in the same order that they were sent [10].

2.1.4 Processing Layer or Cloud Layer

This layer consists of backend services like analytics and cloud computing. Here, the analog data from the devices is converted into a format that is easy to read and analyze. These analysis algorithms can be based on machine learning, artificial intelligence or neural networks. Combining cloud computing with service-oriented architecture (SOA) could provide an efficient middleware for IoT supporting a high level of heterogeneity and flexibility [9].

Additionally, it provides information about the usage of IoT products and handles issues related to the quality of service within operations revealing which device generates problems, revealing data patterns and trends and providing reports and analysis of anomalies [9].

2.1.5 Application Layer or Business Management Layer

The application layer includes people and businesses for collaboration and decision making based on the data derived from IoT computing. It can be merged with the company's ERP system as well as can be made available to the different departments as mobile applications to access data set customizable standards for various activities and make timely changes if necessary. It can include options for auto-actuation or manual actuation for critical machinery works.

3 Shortcomings of IoT in Construction

Usually, construction sites are in remote areas, and their company offices are in cities, constant communication is required between the various workforces within site to the site office as well as site office to home-office and offices of other stakeholder involved in the projects that are located away from the vicinity. Due to limitations in network performance at various places, the connectivity and communications get disrupted in the work environment.

Even in construction sites, basic IoT systems which are meant only for data transfers generally fall short of the expectations as they are not able to provide enough speed and lower latency to undergo primary tasks. Below are a few examples where unnecessary delay causes due to network issues: -

- Data transfer between parties taking longer than expected
- Remote meetings voice and video delay maybe halted
- A significant delay in voice conferencing allowing users to talk over one another
- ERP system resulted in timeouts if remotely accessed
- Slow loading of website and platforms and longer wait time to load or download things

The number of 'things' involved in IoT network is large, so it is much different from a computer network, as the number of nodes increases the complexity of the network increases. In IoT ecosystems, the sensors, actuators and other gadgets are dependent on the responsiveness of the system or network to work effectively. Gerber validates that high latency means delayed responsiveness, and with that comes the inability of things to function to their full capacity [10]. Some IoT systems are designed to respond in case of emergencies, and delayed responsiveness can result in life or deaths. Example: - A delayed response of an actuator intended to close the valve at a certain temperature can result in overheat or even an explosion.

Also working with unmanned machinery in hostile environment needs real-time precision and speed, with present-day network specifications it is not possible to deliver these critical tasks with reliability.

IoT devices usually run on batteries or are self-powered, so they save energy by switching over to energy saving mode, this intern reduced the performance and impacts in slower speeds. Therefore, a low power low latency solution is required [13].

The current system architecture was not designed with IoT in mind. Many systems with their current architecture cannot handle the traffic caused by millions of IoT devices [14]. In construction, most companies are dependent on an Enterprise Resource Planning (ERP) System for project management. These systems have become standard and process designed based on them. For adapting IoT architecture, ERP platforms need to be reconfigured and redesigned. They need an upgrade for the technology which bonds the Layer 1, 2 and 3 of data collection and transmission with the layers 4 and 5 of data analysis and application. (Refer to Figure 3). Though the initial cost of installing an IoT ecosystem is high for small and medium level firms and these firms, need to understand the long-term benefits in decision making and process improvements they will get at later stages.

Additionally, there is an exponential rise in the trend of the number of IoT devices worldwide, and it is expected to rise. Various studies have been conducted to forecast the number of IoT devices, the results of one such study BY Statista estimates that by 2025 almost 76 billion IoT devices will be connected to the internet which is almost three times the devices connected in 2018 [15].

Therefore, combining all these factors there is a critical need for the upgradation of the IoT components and the connectivity skeleton to be able to sustain and meet the growing demand of the future. It is anticipated that the upcoming 5G technology can handle the three connectivity issues, i.e., data traffic, latency, and data transfer issues.

4 Wireless Connectivity: 5G

The International Mobile Telecommunications (IMT) framework of standards is set by the International Telecommunications Union (ITU) for mobile telephony. ITU issued the IMT-Advanced specifications in 2008 as a requirement for the 4G standard. Now, with the growing need of technology upgrade ITU have set a benchmark as IMT-2020 specifications issued in 2017 for the 5G standard.

The 5G technology is divided into three categories based on usage [14]:-

1. **Enhanced Mobile Broadband Service (eMBB):**

It will be used for data-driven applications requiring high data rates across a wide coverage area which will enable platforms for immersive VR and AR applications, 360-degree streaming and Ultra HD video.

2. **Ultra-Reliable Low Latency Communication (URLLC):** This is the second phase of 5G which will have strict requirements on latency and reliability for mission-critical communications, such as autonomous vehicles or the tactile internet.
3. **Massive Machine Type Communication (mMTC):** It will be used for supporting many devices in a small area, which may only send data sporadically such as IoT use cases.

4.1 4G Vs. 5G: Head to Head Comparison

Figure 4 shows a comparison of chief KPIs of 4G (IMT-Advanced) and 5G (IMT-2020) network.

This paper uses the theoretical values of KPIs obtained in a test environment for the 5G and 4G networks; these values can be different than what users practically get depending on the quality of network they are connected to and the connection density.

Some of these KPI's are discussed below in detail.

1. **Very Low Latency:** Reduced latency of the 5G standard is expected to be about 1ms, in that case, construction firms can now hope for real-time operations for autonomous machinery used in critical remote tasks. 4G has a latency of about 30-50ms.
2. **Improved throughput:** Throughput refers to the ratio of data transmitted in a unit time. It is expected that 5G can handle the throughput of

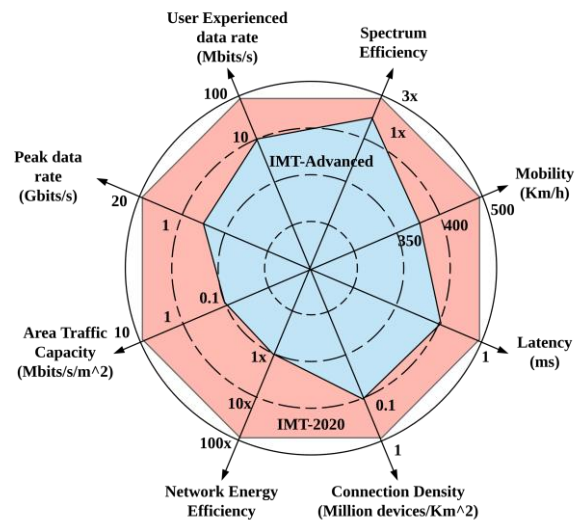


Figure 4. A quantitative comparison of KPIs of 4G and 5G standards (Source: IMT-2020, Network High Level Requirements)

about 10Gbps per connection in comparison to 100Mbps by 4G. That means downloading and uploading speed will be up to 100 times faster. Sometimes having a high-speed network isn't always beneficial especially when it consumes high power, therefore, 5G will phase in new devices like 'Category M1' and 'Narrow Band (NB-IoT)' which will enable lower-power, battery-driven devices as well as far-reaching coverage for remote locations and penetration deep into buildings [16]. These devices will be working on mMTC Technology.

3. **High User Mobility & Improved Reliability:** The eMBB technology of 5G is expected to enhance user mobility up-to 500km/h in moving vehicles, heavy construction machinery. High-quality data at high mobility will allow construction firms to collaborate on various platforms. eMBB will provide broadband access everywhere which will facilitate enhanced connectivity making remote area coverage more reliable.
4. **High user density:** 5G will be able to handle the connection density up-to 1 million connections per square kilometer compared to ten thousand devices by 4G. It is necessary because of the exponential rise in the number of IoT devices per square kilometer. Also, in large construction sites located in cities, where the density of things rises these 5G networks will be able to handle the load smoothly with its Massive-IoT enabling technology.

4.2 Comparative Analysis: Construction Progress Monitoring

Construction managers work under enormous pressure of delivering projects on time, and they tend to monitor schedules more closely and strictly for making better as well as timely decisions. Due to the development of IoT technology, automated daily progress monitoring systems have become a possible (Refer to Figure 1) and as well as necessary tools for managers. Also, BIM platforms require the data to be centralized in a remote server for two reasons, firstly for the collaborative decision making by all the stakeholders and secondly for saving the on-site costs of installing a local server and investing in additional human resource to maintain it. Hence there is a critical need for safe and efficient data transfer mechanism.

Pushkar conducted a study for masonry activity of construction, though this can be easily extended to other construction activities [17]. The data acquisition was made using the commercially available stereo camera as a video file as a part of the input to the planning department, and the setup is as the one describes in Figure 2.

The videogrammetry data size generally depends on the resolution of the video captured and the frame rate but is usually in the range of Gigabytes to Terabytes of data per day. Here is a small piece of time calculation, for the above scenario, the resolution of the camera was set to 720p, and the frame rate was 30fps. Following was the data obtained,

$$\text{Size of 1164 frame video} = 1.3 \text{ GB} \quad (1)$$

Converting the frames into the duration captured using frame rate, Therefore

$$\text{Size of 39 sec video} = 1.3 \text{ GB} \quad (2)$$

$$\text{Hence, Size of 1-minute video} = 2 \text{ GB} \quad (3)$$

Considering that the Camera captures a one-minute video every 30 minutes cycle, for an 8-hour work day, we will require 16 cycles of data capturing (first video captured after 30 minutes from the start).

$$\begin{aligned} \text{Total Data to be captured per day} &= 2 \text{ GB} * \\ 16 \text{ cycles} &= 32 \text{ GB} \end{aligned} \quad (4)$$

Considering the user experience data rates for the transmission of data, over a 4G network the speed is 10 Mbits/s

$$\text{Time to transfer 1GB Data} = 13.33 \text{ Minutes} \quad (5)$$

Over a 5G network, expected speed is 100 Mbits/s

$$\text{Expected Time to transfer 1GB Data} = 80 \text{ sec} \quad (6)$$

*1 Megabit= 0.125 Megabyte

**1 Megabyte = 1000 Gigabyte

The speed being ten times faster can save up to 12 minutes per GB of data transmitted. So, with our single camera, the previous calculation 32GB of data is being transferred to the cloud server in a day then a 5G network can save about 6.4 hours of data transmission time.

Table 1. Time savings for data transfer for multiple cameras

Description	Number of stereo Cameras Collecting data simultaneously									
	1	2	3	4	5	6	7	8	9	10
Data Generated for 1 day (GB)	32	64	96	128	160	192	224	256	288	320
Uploading Time over 4G Network (hours)	7.1	14.2	21.3	28.4	35.5	42.7	49.8	56.9	64.0	71.1
Uploading Time over 5G Network (hours)	0.7	1.4	2.1	2.8	3.6	4.3	5.0	5.7	6.4	7.1
Time Savings (Hours)	6.4	12.8	19.2	25.6	32.0	38.4	44.8	51.2	57.6	64.0

Considering a construction site with ten stereo cameras and daily progress monitoring scenario, we get

the results of time savings as shown in Table 1. Results show that instead of 71 hours the 5G network can transfer the same data over the cloud in 7 hours which will help construction managers to get the analyzed results as a report the next morning itself.

As demonstrated in Figure 2 construction sites consist of many activities going parallelly, there will be many sensors capturing the data simultaneously. The amount of data obtained will be huge, even the BIM files which are to be sent over the cloud for processing are of considerable size and takes time for uploading through the different layers of IoT structure as shown in Figure 3. The 5G data speeds can help us to save a considerable amount of time in data transfer and hence resulting in timely decision making.

If sensors are placed for real-time monitoring purpose over a 5G network, the latency will be in the order of 1ms, which is equivalent to the real-time scenario, whereas using a 4G network gives a latency of 30-50ms. The 5G network is expected to provide more reliability than a 4G network, so the data packets will not be lost during the transmission which sometimes results in an erroneous or incomplete data while processing.

This speed of data transmission, lower latency, availability to bear high connection density makes the 5G network more efficient and reliable than the present 4G network. It can result in a considerable amount of savings in time and cost by facilitating timely decision making.

5 Conclusion

Implementation and effective use of IoT in the construction environment will not be an easy task. Within the next ten years, IoT networks will face prominent challenges because the networks will denser, more complex and heavily loaded than today. The continuous evolvement of IoT is needed along with developing and embracing new paradigms as it should continue to meet consumer and enterprise expectation and mission-critical applications in the coming future. However, a properly planned map to its deployment will smoothen the transition of the construction industry into the IoT ecosystem.

One of the challenges is the need for a faster, reliable, robust connectivity network. 5G implementation can be one of the technological upgrades to overcome these issues. The future connectivity standards will focus on improvement in connection density to handle the massive number of IoT devices, pervasive coverage to reaching challenging locations, low-power consumption and reducing network complexity. These technological challenges if dealt with planned and proper approach will make an

ambient environment for wide-scale 5G adoption. In addition to this, the governments and private players should join hands to understand the economic growth the 5G standard can bring and should work closely for all the necessary technological upgradation necessary.

IoT has prospects to be the backbone of the construction industry, and therefore, there is a significant need to understand and address the challenges and barriers in IoT implementation and usage to foresee a future where IoT will be embedded as a ubiquitous tool to support the businesses and projects.

The future research can be focussed upon the applications of IoT in construction management that have been proposed in this paper. These applications will collect data from numerous resources and will have to integrate it collaboratively for better decision making. The five layers of IoT are the backbone to any IoT platform, and each has a high potential for exploration and improvement. The data processing capabilities using cloud computing and tools such as AI and Machine learning have shown a significant trend in usage and are a potential area of research to make IoT further useful for decision making.

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