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A Data-Driven 5S Management Model Using IoT for Industrial Applications

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Abstract

The 5S methodology (Sort, Set in Order, Shine, Standardize, Sustain) is widely adopted in lean manufacturing to improve productivity and workplace organization. However, traditional 5S implementation relies heavily on manual audits and supervision. This paper proposes an Internet of Things (IoT)-based 5S management system that enables real-time monitoring, automated compliance tracking, and data-driven decision-making. The proposed system integrates sensors, RFID, cloud computing, and dashboard visualization to enhance operational efficiency and sustainability. Experimental results demonstrate improved compliance rates, reduced search time, and enhanced workplace safety.

Keywords: 5S, IoT, Smart Manufacturing, Lean Management, Industry 4.0, RFID, Automation

I. INTRODUCTION

5S is a system to reduce waste and optimize productivity through maintaining an orderly workplace and using visual cues to achieve more consistent operational results. Implementation of this method "cleans up" and organizes the workplace basically in its existing configuration, and it is typically the first lean method which organizations implement.The 5S pillars, Sort (*Seiri*), Set in Order (*Seiton*), Shine (*Seiso*), Standardize (*Seiketsu*), and Sustain (*Shitsuke*), provide a methodology for organizing, cleaning, developing, and sustaining a productive work environment. In the daily work of a company, routines that maintain organization and orderliness are essential to a smooth and efficient flow of activities. This lean method encourages workers to improve their working conditions and helps them to learn to reduce waste, unplanned downtime, and in-process inventory.

A typical 5S implementation would result in significant reductions in the square footage of space needed for existing operations. It also would result in the organization of tools and materials into labeled and color coded storage locations, as well as "kits" that contain just what is needed to perform a task. 5S provides the foundation on which other lean methods, such as TPM, cellular, manufacturing, just in time production can be introduced.

Despite its widespread adoption across manufacturing and service industries, conventional 5S implementation faces several limitations. These include reliance on manual monitoring, subjective audit evaluations, inconsistent compliance, and difficulty in sustaining improvements over time. As industries transition toward digital transformation under the paradigm of Industry 4.0, there is growing interest in integrating smart technologies to enhance traditional lean practices.

The Internet of Things (IoT) refers to interconnected physical devices embedded with sensors, communication modules, and software that enable real-time data collection, monitoring, and control. In industrial environments, IoT facilitates asset tracking, environmental monitoring, predictive maintenance, and data- driven decision-making through cyber-physical systems.

Integrating IoT with the 5S management system introduces a new dimension of digitalized workplace organization. Smart sensors, RFID tags, machine vision systems, and cloud-based dashboards can automate monitoring of workspace cleanliness, tool placement, material flow, and compliance with standardized procedures.

The convergence of 5S principles with IoT technologies represents a significant step toward intelligent lean management systems. It aligns operational discipline with digital transformation strategies, paving the way for smart, efficient, and sustainable industrial workplaces.

II. RELATED WORK

IoT architecture in a 5G system is shown in Figure 1. In [6], [7], the authors discuss a 5G IoT architecture where smart IoT sensors for different applications could be connected to an IoT gateway through different wired and wireless networks. This gateway has the task of collecting and forwarding all the information between the IoT devices and the 5G base stations through a wireless link. 5G communication links provide the much needed URLLC and eMBB capabilities to the IoT system through the use of 5G NR technology with efficient numerology selection and mmWave communication technology [8]. However, network mobility, coverage, and reachability remain open research areas that needs to be addressed for ubiquitous communication. Also, as discussed by authors in [9], 5G standards are still evolving to address the challenges related to scalability, latency, and reliability. In [10], the authors discuss that achieving stringent performance requirements for diverse IoT applications is a major challenge to be resolved. Thus, there is a critical need for studying and developing the systems that provide these capabilities. Given the wide range of services and performance offered by 5G networks, it is paramount that any development and study of 5G system is done on a platform that offers endto-end simulation capabilities. Building a real-world cellular network for testing is often associated with infrastructure complexities. The Platforms for Advanced Wireless Research (PAWR) program has helped build one such wireless testbed at the University of Utah in Salt Lake City called POWDER [11], that offers a remotely accessible end-to-end software-defined platform to conduct such research. However, discrete-event network simulators offer a better and more scalable alternative for analyzing complex networks and developing new protocols. In this paper, we develop a 5G-IoT architecture by extending the functionality of the Simu5G simulator that provides a 3GPP compliant 5G simulation model library based on the OMNeT++ framework. Such end-to-end network simulators are great for performance analysis of 5G systems as they allow full-stack simulation using models for every Fig. 1. 5G-IoT Architecture layer of the protocol stack, network equipment, as well as application logic. This ability to simulate the whole network stack plays a crucial role in understanding many new features of 5G networks. Along with OMNeT++, another widely used network simulation framework is ns-3 [12] that allows users to develop their own model libraries. Apart from Simu5G, which is based on the OMNeT++ framework and discussed in more detail in the next section, the other popular end-to-end simulation tools for 5G networks are based on ns-
3. The 5G-LENA [13] model library uses the ns-3 framework and builds upon the LENA (LTE-EPC Network Simulator) 4G LTE library [14]. However, the 5G-LENA library mainly focuses on

implementing the MAC and PHY layers of the 5G network stack. The ns-3 mmWave module [15] was developed before 3GPP 5G standards were finalized and thus is not fully compliant with the current standards.

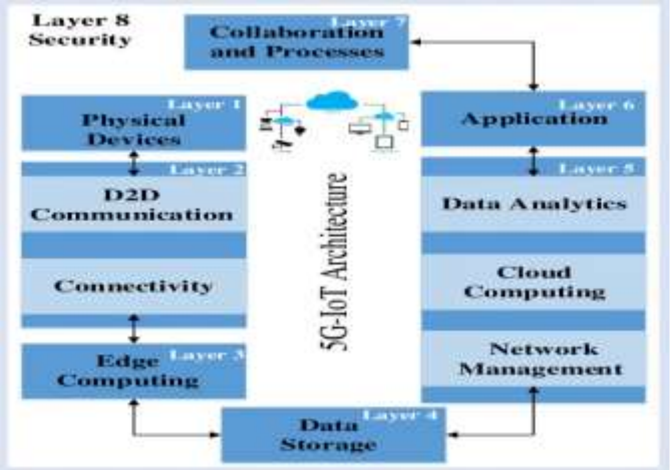


Figure1: The proposed 5G-IoT architecture.

III METHODOLOGY

This section describes a structured methodology for designing and implementing an **IoT-enabled 5S Management System**. The approach combines traditional 5S principles with smart sensing, data analytics, and real-time monitoring aligned with Industry 4.0 practices.5G has significant changes to architecture and capabilities relative to 4G. With regard to 5G NR and the access network, there are three major capabilities delivered by 5G that will be of interest for IoT:

1. Increased bandwidth – The enhanced Mobile Broadband (eMBB) capability provides theoretical speeds of up to 10Gbit/s.
2. Support for massive IoT deployments – the massive Machine- Type Communications (mMTC) features provide for supporting many more devices per cell, with additional features for supporting Low Power Wide Area (LPWA) deployments, for instance much longer battery life.
3. Lower latency and reliability across all applications – The capabilities referred to as Ultra Reliable Low Latency Communications (URLLC) reduce the time it takes messages to travel over the network, and increases the reliability of delivery.

Enhanced Mobile Broadband (eMBB) Theoretically 5G New Radio offers speeds of up to 10Gbit/s but the reality is that the experienced maximum speeds by a single user will typically be 100-200Mbit/s. This represents a significant improvement (about five-fold) over LTE. The predominant benefit of this capability is to give a richer experience for mobile broadband usage. Most of that relates to video, gaming and other high bandwidth streaming. It also makes mobile a viable alternative to fixed line broadband for more households.

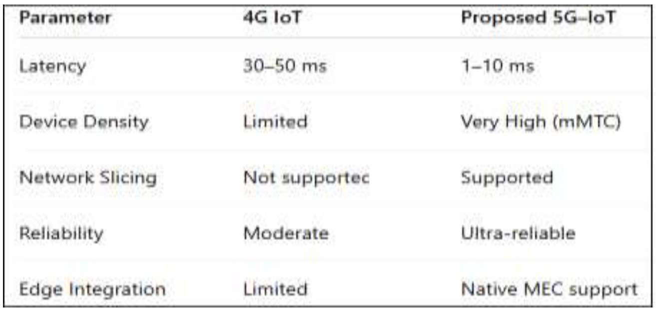
Massive Machine-Type Communications (mMTC)

This capability set is aimed specifically at IoT. The headline functionality is the ability to support at least 1 million devices per square km (up from 100,000 with LTE).The 5G standard also incorporates, and builds upon, a set of existing standards aimed specifically at supporting low bandwidth, low power, IoT devices, including features such as power-saving mode (PSM) and extend Discontinuous Reception (eDRX) which extend battery life. These LPWA (Low Power Wide Area) technologies, NB-IoT and

LTE-M are discussed at length in another of our Hot Topics pages: Low Power Wide Area Networks. In addition, within 5G Release 17 is 5G RedCap (Reduced Capability) which sits somewhere between full 5G NR and the LPWA technologies.

Ultra-Reliable Low Latency Communication (URLLC) Under the banner of URLLC 5G promises two changes that will open up certain use cases, particularly associated with IoT. The first is reducing latency. Latency refers to the delays in getting data packets from point A to point B. This is typically not a major consideration for, say, video streaming, but it is for gaming, where responsiveness is important. The time it takes for a message to traverse the network from the games console to the server and back again is critical to the user's enjoyment. It is also a critical component of some of the most sophisticated 5G use cases that are proposed, such as remote surgery or managing autonomous vehicles. Another example is energy grids, where split second control might be necessary. The responsiveness of a device to the messages that are being sent to and from it needs to be very close to real-time. Clearly, in many of these examples, the requirement for low latency is associated with critical systems where reliability is also paramount. Hence low latency is bundled with ultra-reliability as a requirement.

Table I: Comparison with 4G-Based IoT Systems



Parameter	4G IoT	Proposed 5G-IoT
Latency	30–50 ms	1–10 ms
Device Density	Limited	Very High (mMTC)
Network Slicing	Not supportec	Supported
Reliability	Moderate	Ultra-reliable
Edge Integration	Limited	Native MEC support

IV. 5G-IOT ARCHITECTURE AND SIMULATION

ENVIRONMENT This section briefly discusses the OMNeT++ framework and the Simu5G model that can be used for 5G New Radio (NR) user plane simulations. We also discuss the specifics of the proposed architecture to support IoT experiments in the 5G system along with our simulation design. Simu5G is built on a widely used discrete-event simulation framework called OMNeT++ that can be used to model both wired and wireless networks, among others. Modules are the basic building blocks in the OMNeT++ framework and can be simple modules, or they can be combined to create more complex compound modules. They can also be linked through their interfaces called gates with links that are known as connections. Modules use messages to communicate with each other, and simple modules are programmed to exhibit a specific behavior on receipt of these messages. This model behavior is written and programmed in C++. OMNeT++ uses NED or Network Description language to define the modules along with their gates and connections. The parameter values needed to initialize a model are defined in an initialization (INI) file. It also provides an Eclipsebased Integrated Development Environment (IDE) to facilitate editing and debugging. Simu5G makes use of the popular INET model library in OMNeT++ that implements models for various communication protocols, network nodes, connections, among others. Thus, by leveraging features of the OMNeT++, INET, and Simu5G libraries, one can simulate complex endto-end scenarios using different networks with 5G systems. Figure 2 shows the 5G-IoT Architecture using Simu5G. The NR capabilities of the 5G RAN in Simu5G are simulated in two main compound modules NrUe and gNodeB. The functionalities of the RAN are implemented as a stack of four protocol layers, which are the Packet Data Convergence Protocol (PDCP) layer, Radio Link Control (RLC) layer, Media Access Control (MAC) layer, and Physical (PHY) layer. Thus, the NrUe and gNodeB modules consist of four submodules (NrPdcp, NrRlc, NrMac, NrPhy), each representing a layer in the protocol stack. They also consist of an Ip2Nic submodule that can act as a bridge between the IP layer and the PDCP layer. The five submodules combined together make a compound module called NrNic representing the radio network interface. The NrUe module also implements the upper layers (UDP and IP layers) of the protocol stack using the INET library.

The Simu5G model library offers highly realistic and customizable channel models for modeling physical transmission. The carrierAggregation module in Simu5G can be used for simulating communication on multiple carrier component frequencies. We can vary key parameters like the carrier frequencies, bandwidths, number of resource blocks, etc., using the NED and INI files. Using this module, we can also adjust the numerology that varies the subcarrier spacing and the slot duration of 5G signals which is critical for enabling URLLC and eMBB services. As part of the 5G core implementation, Simu5G provides a UPF module that is responsible for routing IP packets between the data network and the gNodeBs through the GTP (GPRS Tunnelling Protocol) tunnels. The UPF module can be directly connected to a gNodeB resulting in the standalone architecture deployment scenario. The 5G-IoT architecture, as shown in Figure 1 consists of a mobile IoT gateway that can be used to connect the 5G base station to the end IoT devices, which often have very constrained capabilities. These gateways could also perform data aggregation on the packets coming from the various sensors, actuators, etc., in the IoT network [8]. The radio functionalities of the IoT gateway closely resembles that of a UE module in the 5G system. However, the gateway has the additional responsibility of forwarding packets to and from the IoT devices that are attached to it. As discussed above, the Simu5G library implementation of the NrUe module includes only the radio interfaces and lacks additional network interfaces for connecting to IoT devices in the network. Hence, the NrUe module was extended, and wired network interfaces were added parallel to the existing radio interface as shown in Figure 2. We also introduce a new compound module to represent the IoT devices attached to the IoT gateway. This new module emulates the protocol stack of a standard host module in INET. It also includes a novel submodule responsible for associating itself with a gNodeB and registering its IP address in the system. Our implementation is capable of handling multiple IoT gateways with multiple IoT devices connected over Ethernet links for network scalability and performance. The standard implementation of Simu5G uses the address of the destination UE at the UPF to find out the connected gNodeB in the downlink direction. The UPF then uses this gNodeB address as the tunnel end-point identifier (TE-ID) to create the GTP-U tunnel. However, in an IoT scenario, the end devices are no longer the UEs but are the IoT devices that have no direct connection to the gNodeBs as shown in Figure 3. Thus, the system is enhanced such that each IoT device in the system has an associated gNodeB, depending on the IoT gateway/UE to which it is connected. The UPF can now know which IoT device is connected to which IoT gateway and hence to which gNodeB. Also, the gNodeB uses the information about its connected IoT gateways/UEs for scheduling in the MAC layer but does not have information about the IoT devices. Thus, the system is further developed, such that the gNodeB can now know which IoT device is connected to which IoT gateway and can use that information for scheduling. We also enable IP layer forwarding at the IoT gateway such that the packets are routed to the correct IoT device.

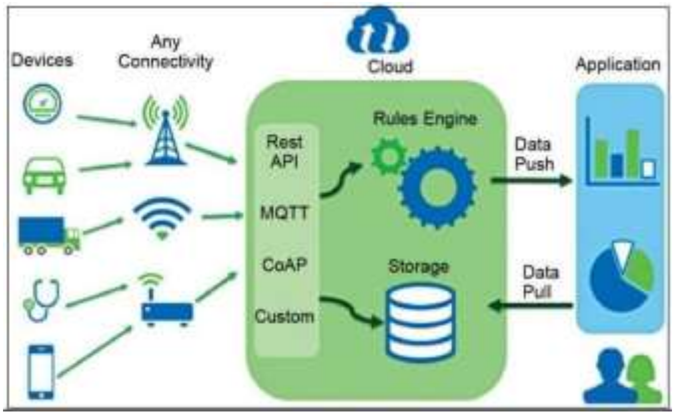


Figure:2 Data collection in IoT networks

CONCLUSION

The proposed IoT-based architecture transforms the traditional 5S management system into a smart, automated, and scalable digital framework. By integrating sensing technologies, secure communication networks, cloud analytics, and interactive dashboards, the system ensures real-time visibility, continuous improvement, and enhanced operational efficiency in modern industrial environments. The literature shows substantial research on 5S as a lean tool and on IoT in manufacturing, but integration of IoT with 5S management systems is still emergent. Most research today explores IoT with lean manufacturing broadly, with very few focusing narrowly on IoT-enhanced 5S systems. There's clear potential for such integration to provide continuous, data-driven workspace organization.

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