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A **Comprehensive Approach for Connecting LTE Networks to IoT Devices**

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Abstract: Connecting IoT devices to an architecture that allows for end-to-end service integration is becoming more important as the number of devices utilizing the Internet of Things (IoT) continues to rise. From 10 billion in 2015 to 34 billion in 2025, the number of internet-connected devices is expected to see tremendous rise.IN THE LONG RUN, LTE networks will be the most suitable ally to meet the needs of the same in terms of service. The signaling overhead in IoT systems, however, will increase at an exponential rate as the number of IoT devices continues to rise. Consequently, the signaling overhead in LTE networks will rise. Because of the high volume of data sent and received by IoT devices, the current protocol stack of LTE networks is ill-equipped to manage the surge in signaling traffic that these networks generate. An efficient protocol stack for managing LTE-based Internet of Things traffic is suggested in this study. The development of a unique protocol stack that can include IoT traffic into LTE systems is suggested with particular emphasis. Before proposing a new protocol stack to support IoT traffic on LTE networks, the thesis discusses the many shortcomings of the current stack. To address the shortcomings of current scheduling schemes and include the suggested protocol stack, a new scheduling method based on queuing models is also suggested.

Keywords*: IoT (Internet of Things), LTE (Long-Term Evolution) , Protocol Stack, Signaling Overhead, IoT Traffic Management, Queuing Model, Scheduling Scheme, Network Architecture*

Introduction

The proliferation of IoT devices spans various sectors, including healthcare, smart cities, industrial automation, and home automation. For instance, wearable health monitors track vital signs and transmit data in real-time, smart meters optimize energy usage, and connected cars enhance transportation safety and efficiency[1][2].

The rapid growth of IoT underscores the need for robust and scalable connectivity solutions to handle the increasing data and signaling demands. IoT devices require reliable, low-latency communication to function effectively, making the choice of underlying network technology critical. Long-Term Evolution (LTE) technology has become a cornerstone of modern wireless communication, offering high data rates, low latency, extensive coverage, and robust security features. LTE is widely used in mobile communication, providing high-speed internet access to smartphones and tablets[3]. It also supports broadband access in rural and underserved areas, ensuring wider connectivity[4].

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The advantages of LTE make it a suitable candidate for IoT applications. Its ability to provide reliable, high-speed data transmission with low latency is crucial for many IoT use cases, such as real-time health monitoring and smart traffic management. Furthermore, LTE's widespread infrastructure and established ecosystem offer a strong foundation for integrating IoT devices seamlessly[5]. Signaling in LTE networks involves the exchange of control information to establish, maintain, and terminate connections. With the surge in IoT devices, the signaling traffic has increased significantly. IoT devices frequently exchange small packets of data, leading to a high volume of signaling messages[6]. This increase in signaling overhead can strain LTE networks, resulting in reduced performance and higher latency[7].

The existing LTE protocol stack, designed primarily for mobile broadband, faces challenges in handling the unique traffic patterns of IoT devices. IoT traffic often consists of small, sporadic data transmissions, which differ from the continuous, high-volume data streams typical of mobile broadband. The current protocol stack may not efficiently manage these sporadic transmissions, leading to inefficiencies and potential bottlenecks in the network.Scalability is a critical concern as the number of IoT devices continues to grow[8]. LTE networks must accommodate millions of devices simultaneously, each with its own connectivity and data transmission requirements. The current infrastructure may struggle to maintain performance and reliability under such conditions, necessitating a scalable solution that can support future IoT growth.To address the limitations of the existing LTE protocol stack, this work proposes a novel protocol stack specifically designed for IoT traffic[9]. The new protocol stack aims to optimize the handling of IoT signaling and data transmissions, improving efficiency and reducing overhead. Key features include enhanced signaling protocols and optimized data transmission mechanisms tailored to IoT traffic patterns.An advanced queuing model-based scheduling scheme is also proposed to manage IoT traffic more effectively[10][11]. This scheme prioritizes IoT signaling and data packets based on their importance and timing requirements, ensuring that critical IoT data is transmitted with minimal delay. The scheduling scheme aims to balance the load on the network, preventing congestion and maintaining high performance.The proposed protocol stack is designed to enhance the LTE network's capabilities for IoT traffic[12][13]. It includes new signaling protocols to reduce overhead and optimized data transmission mechanisms to handle small, sporadic IoT packets more efficiently. The design also incorporates security features to protect IoT data and ensure privacy[14]. The advanced queuing model prioritizes IoT traffic based on various factors, such as data type, urgency, and device importance. The scheduling algorithm integrates with the queuing model to allocate network resources dynamically, ensuring that critical IoT data is transmitted promptly. This approach helps maintain network performance even under high load conditions[15]. Implementing the proposed solution involves several practical considerations, such as compatibility with existing LTE infrastructure, scalability to support future growth, and security to protect IoT data. The implementation strategy includes deploying the new protocol stack and scheduling scheme in a phased manner, allowing for gradual integration and testing[16].

As mentioned before, the success of Internet of Things (IoT) traffic in LTE networks is heavily dependent on bandwidth control. Without which the network operators may find it impossible to fulfill the rising demand of customers for multimedia services, and therefore resulting in significant revenue loss. There are a lot of factors that make this a difficult challenge that requires careful thought. One such serious problem is the channel quality for mobile consumers.

Every MS has a somewhat different channel quality. As a general rule in wireless communication, the channel quality is higher for MS that are near to the base station and worse for MS that are further away. Having MS so far removed from BS is not, however, MS's fault. The channel quality of the MS is affected by various elements, such as interference from other users and barriers, among others. Estimating the state of the channel and allocating resources accordingly is a common task for bandwidth management techniques. In our instance, the issue of fairness arises because the MS adjacent to the BS has better channel conditions and thus higher system throughput than the MS farther away, which is problematic. It is crucial to keep fairness in mind while designing bandwidth management methods.

With LTE, fairness becomes a much bigger challenge since it incorporates both intra- and inter-class traffic. Since LTEs are designed to accommodate a variety of multimedia services with different quality of service needs, it is crucial to take these requirements into account in order to satisfy the users. Since LTE systems are primarily intended to manage multimedia traffic, which causes the network to get clogged rapidly, this is a significant concern that needs to be taken into account when designing bandwidth provisioning techniques.

Adding more complexity to the scheduler's duty is the fact that we must simultaneously manage several users with varying bandwidth needs and services. A major challenge for LTE networks is the streaming of voice applications. Despite having their foundation in packet switching, LTE-A systems stream voice packets via circuit switching. The reasoning for it is straightforward. Since speech packets are very delay-sensitive, LTE resorts to circuit switching in order to stream voice, but this also introduces all of circuit switching's drawbacks. A significant amount of valuable bandwidth is squandered when LTE networks transition to circuit switching for voice streaming applications.

Last but not least, supplying customers who do not generate income is a challenge with bandwidth management in LTE. Depending on factors including channel quality, base station buffer size, and customer willingness to pay, network operators incur varying degrees of revenue loss while servicing consumers.

A well-designed bandwidth management strategy should take these revenue losses into account and work to minimize them.11 and 12 It is very unlikely that the LTE system could support a new architecture or protocol such as the Internet of Things (IoT) due to the severe bandwidth constraints that the LTE now faces. To accommodate the IoT platform in LTE systems, it is required to construct a different scheduler class and establish a distinct protocol stack.

Not to mention that the IoT platform generates so much signaling overhead that LTE networks just cannot support it. An innovative protocol architecture has been developed with the goal of reducing the amount of signaling messages sent by user equipment (UE) during LTE join attempts. As seen in Figure 1, the current architecture is shown schematically.

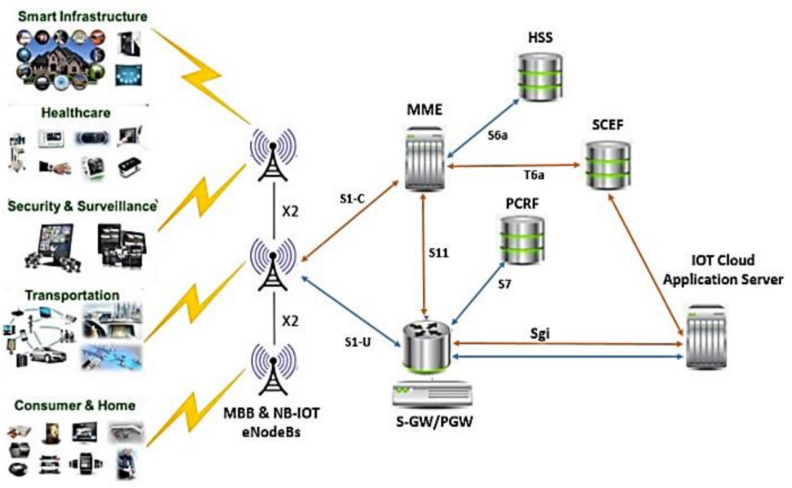

Fig 1.Existing IoT LTE network architecture

Current approaches address just a subset of these challenges; as a result, they are unable to improve BWAS performance or user happiness to their full potential. All of these obstacles should be easily accounted for and balanced out using a protocol stack-based bandwidth allocation scheme.

See Figure 2 for an illustration of an LTE reference architecture.Within LTE networks, you won't find any Radio Network Controller components. The RNS/BSC tasks have been assigned to either the eNodeB or the MME. Subsequently, the aggregation and backhaul layers are reduced in number. To facilitate end-to-end communication amongst the many components of an LTE network, Internet Protocol (IP) is used as the interface at the network layer. In the 2G/3G packet network, this lowers the level of hierarchy. Additionally, end-to-end IP simplifies the administration and design of each sub-domain. The functional breakdown is another important difference; it separates the multiple network pieces that make up the LTE packet core, which are the control plane and the bearer plane. The primary purpose of carrying it is to maximize its functionality so that it can operate independently. Wireless operators may take use of this decoupling method while developing the EPC network, allowing them to install EPC bearer and control plane components only when they are required. Because of this leeway, service providers may build their LTE core networks in ways that were previously unimaginable with older networks. Because of this, the EPC's performance, scalability, and operational efficiency are all optimized, which means that the service providers generate more income. Because of all these things, LTE is the ideal network technology for IoT.

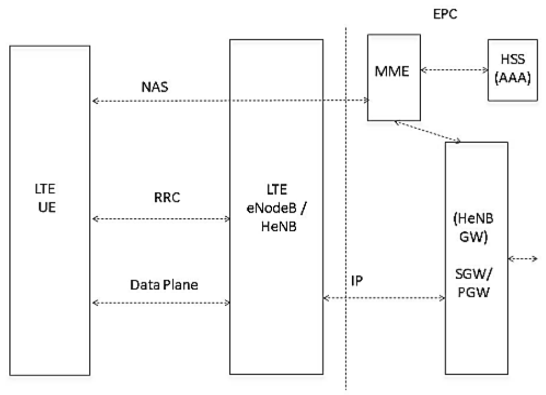

Fig 2. Conventional LTE Architecture

Reduced Control Plane Processing Protocol (RRCP)

A set of protocols for LTE Attach with Reduced Control Plane Processing is proposed in this paper. As seen in Figure 3, our new rational entity, buffer, is used in the LTE network. Secure channels will be set up between the "LTE-eNodeB and buffer" and the "MME and buffer," and the buffer will be a reliable partner with other parts of the network. In a perfect world, the network service provider would have the Buffer as a trusted partner. Our suggested streamlined Attach process consists of three main steps. While the suggested RCPP strategy is successful upon a UE's return from SLEEP mode, it fails miserably when fresh UE attempt to join the network for the first time. It is possible to break the process down into three sections. Part one involves the UE trying a standard Attach process. In the second step, the buffer will undertake the Attach operation between itself and the MME after intercepting certain messages meant for the eNodeB. This prevents the UE and eNodeB air-interface communications from being duplicated or sent more than once. Authentication between the UE and the EPC is performed in the third step. Up to the ATTACH process, the RRCP protocol may only be discussed in context. Even while the Buffer may simulate the UE's actions, it can only do so until the Attach is finished. The remaining activities are entirely under the control of the network service provider; the UE has no authority to intervene. The UE's ability to access the network interface will be revoked if it is determined that the security credentials are invalid. Below, we'll go over the RRCP protocol and how each LTE architectural module works. Typically, when an LTE user equipment (UE) awakens from sleep mode, it immediately sends the Attach request message to begin the Attach operation. After the UE sends an Attach message, the MME passes it on to the HSS, which verifies the UE's identity. Following the usual Attach process, the HSS tells MME of the Authentication Vector(s) it has generated after receiving the IMSI from the UE in the request message. The UE is once again given with a shared key K by the MME in the RRCP protocol. It is up to the MME to decide which AV to use if the HSS generates more than one in a given round. Authentication Request messages are sent from MME to UE as part of the standard process. But in the RRCP approach, the buffer intercepts the unencrypted Authentication message. The message's IMSI is extracted from it by the buffer. After that, the buffer uses the IMSI and KSIASME to ping the MME[17]. Pressing the command to enter NAS Security Mode is critical. To do the same, you may use an altered attach message. The MME's operations will be altered in several ways as a result of this. The NAS security process will now be initiated by the MME. The MME is responsible for sending the NAS Security Mode Command to the UE. As part of the suggested plan, the buffer would keep track of the details of the traversal message and intercept it. Through the encrypted connection, the buffer is additionally informed of the uplink and downlink counts. The buffer will eventually calculate the UE's encryption and integrity check keys. Additionally, the MME is responsible for creating the NAS keys and relaying them to the buffer. So yet, the procedure has not progressed to the point where the UE and the serving and packet gateways have verified each other. So, until the authentication handshake is over, we hold a flag open. The MM will approve the UE's request when the authentication procedure is finished by generating the NAS message with the RRC Security Mode Command. The buffer additionally prepares the RRC channel and intercepts the Accept message at the enodeB with the RRC Security Mode Command. Additionally, the RRC Security Mode Command's integrity check is executed by the buffer. An unresetable flag indicates that the authentication procedure is not complete. to the UE[18]. The use of an additional encrypted channel makes this possible. The buffer contacts MME to get the IMSI keys K and KASME. After the MME receives both keys, it updates the buffer with the new values. Once again, this takes place via the previously stated security channel. The network service provider retains ownership of the buffer even after the key K exits the attach operation. From now on, the buffer will create the AUTN message every time the same UE wishes to join the network. The buffer also acts as a validater for both previous and current AUTN messages. Additionally, the buffer is responsible for calculating and communicating the updated authentication response messages to the MME. It is at the MME that the buffer's response message is checked. In turn, this lowers the air interface overhead.

By now, you may have noticed that the buffer has begun to mimic the majority of the UE-generated messages. Nevertheless, the UE's authentication is not yet complete. After the authentication is finished, the MME sends a fresh RRC signal to the UE. Parameters such as RAND, AUTN, KSASME, and NAS counters will be encrypted and carried in the RRC communication.After receiving this message, the UE will create a response message and transmit it to the eNodeB, which will then relay it to the MME. Resetting the flag and authenticating the UE occurs when the response value (RES) matches the anticipated response. All of an Internet of Things device's configuration information is erased from eNodeB once it goes into sleep mode under the generic LTE architecture[19]. Equally deleted from the eNodeB are all of the security keys. Alternatively, the parameters are left in the proposed RRCP protocol. The MME retains a portion of the UE's configuration. The KASME key is saved in the buffer so that it doesn't have to get them from the MME every time the gateways need to utilize them. Additionally, the buffer stores the NAS counters. Life becomes really easy with KASME In the next part, we will go over the roles played by the UE, eNodeB, MME, and HSS during the LTE attach operation in the RRCP protocol stack. In addition, the other parameters may be obtained directly from the buffer without accessing the user endpoint, which simplifies the control plane, improves bandwidth efficiency, and decreases time[20].

According to GSMA, IoT traffic is expected to see exponential growth in the next years. By 2020, there will be over 24 billion gadgets that can communicate with each other [57]. Additionally, Machine Type Traffic, distinct from Human Type Traffic, is anticipated to be generated by IoT devices [58].Data sizes for machine-type traffic are often tiny, and the devices involved are typically dormant; they only activate or send data when there is data to broadcast. In the future, these patterns will usher in a new era of data traffic, characterized by heavy traffic generation by the control plane and subsequent severe congestion in evolved node B (eNB) and the mobility management entity (MME) [59]. Because of the dramatic growth in signal traffic, this will cause network service providers' costs and overhead to rise[21]. As the Internet of Things (IoT) continues to expand, the best cellular network to handle the traffic generated by the IoT will be Long Term Evolution (LTE)[22]. Web surfing, file transfers, and video streaming are examples of human traffic conditions that conventional LTE networks are built to manage. In LTE, you may toggle between two radio states: RRC_Connected and RRC_Idle. Only when the RRC_Connected state is present does the traffic in any of the previously described patterns occur. Quite a bit of energy will be saved here. When it comes to traffic from the Internet of Things (IoT), however, the patterns will be entirely different, necessitating that the LTE toggle between the RRC_Connected and RRC_Idle states. This is due to the fact that the gadgets would intrinsically produce massive bursts of traffic, overwhelming the LTE networks with signaling demands. So, to accommodate the IoT traffic, we must meticulously express the ON/OFF states in LTE. Due to two main reasons, conventional scheduling algorithms will fail miserably when it comes to managing traffic from IoT devices, whose traffic patterns are drastically different. Keeping the scheduler's pointer from constantly bouncing between RRC_Connected and RRC_idle modes is possible if the scheduling method is assumed to be in RRC_Connected mode at all times. Nevertheless, this will significantly raise the power consumption or deplete the power of the UE devices. On the other side, when the scheduling pointer is set to RRC idle mode, the IoT devices' traffic patterns will need frequent channel configurations. This is because the devices will transmit brief bursts regularly, which will increase the latency and ultimately degrade performance. Medical health monitoring, surveillance, and vehicular communication are all examples of delay-sensitive IoT traffic that will be interrupted. Because of this, it is critical to develop a scheduling algorithm that can handle both delay-sensitive and delay-insensitive Internet of Things (IoT) traffic while also controlling the system's power consumption, latency, and bandwidth. In order to optimize the performance of LTE networks to meet the traffic demands of IoT devices, we provide a dynamic channel aware/QoS unaware uplink scheduling (DCA) algorithm that can be integrated into the LTE system's eNodeB[5][6]. Effective Bandwidth Allocation Scheduling is what we're aiming for, therefore we use network calculus to create a dynamic uplink scheduling method that takes channel awareness and quality of service into account. To make things clearer, we will go over the network architecture and the traffic pattern of the Internet of Things (IoT) before we talk about the scheduling scheme and markov analysis. The Internet of Things (IoT) network architecture is shown in Figure 3.

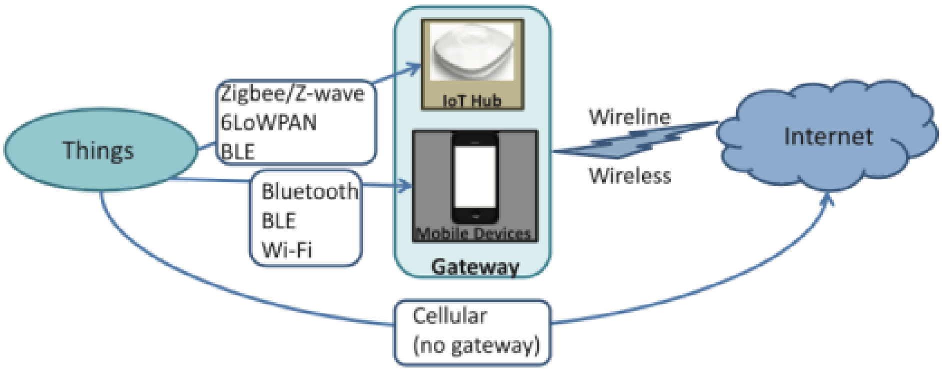

Fig 3: Network Architecture of IoT

Internet of Things (IoT) devices often link to the internet or cloud via a gateway or cellular network. The power consumption of the gadget increases when it is linked over a cellular network. However, if they are linked to the internet via a gateway, also known as an IoT hub, then the hubs will be tied to a power source. Internet of Things (IoT) devices often make use of protocols such as ZigBee, Bluetooth low energy, Wi-Fi, Z-wave, and sometimes even mobile gateways[15][16].

Conclusion

The existing LTE protocol stack, however, is not equipped to handle the increased signaling traffic generated by these devices. This thesis has identified the limitations of the current protocol stack and proposed a novel protocol stack designed specifically to accommodate IoT traffic. The proposed stack includes an advanced queuing model-based scheduling scheme to efficiently manage the increased signaling overhead. This new approach ensures seamless integration of IoT services within LTE networks, enhancing network efficiency and scalability. By addressing the signaling challenges, the proposed solution significantly improves the performance and reliability of LTE networks in IoT environments. The novel protocol stack and scheduling scheme provide a robust framework for future IoT connectivity, ensuring that LTE networks can meet the demands of a rapidly expanding IoT ecosystem. This comprehensive approach paves the way for more efficient, scalable, and reliable IoT-LTE integration, supporting the continued growth and innovation in the IoT space.

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