Preparing Wi-Fi Networks for Novel Services in Smart Infrastructure

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***Abstract*—Wi-Fi will be the preferred access network in smart infrastructure, which is a considerably cheaper alternative of mobile broadband. Emerging services such as Internet of things (IoT), virtual reality (VR) and ehealth, which require carrier-grade quality have shifted data traffic. Therefore, smart infrastructures need an extensive analysis of application requirements and user expectations. This paper presents the concept of cumulative network parameter monitoring and analysis in order to improve overall Wi-Fi quality in smart infrastructure. The proposed concept incorporates security and privacy in addition to generic performance parameters. The cumulative network parameters monitoring and analysis investigates various parameters in order to assess overall quality rather than individual performance parameter monitoring for a particular service. Hence, cumulative network parameter monitoring and analysis concept can establish a baseline to estimate user acceptability objectively rather than costly subjective assessments.**

***Index Terms*—Wi-Fi; quality; QoE; security and privacy; smart infrastructure.**

I. Introduction

In recent years, Wi-Fi is a preferred network connectivity technology, which is a considerably cheaper alternative to mobile networks in order to deliver broadband connectivity to end-users. Wi-Fi networks will be the main medium as an access network such that 658 million households will have Wi-Fi networks by 2023 while 364 million households will have more than one access point [1]. The cellular traffic offloading, TV everywhere, transportation Wi-Fi, Internet of things (IoT), virtual reality (VR), augmented reality (AR), eHealth and managed service in mobile devices have transformed traditional Wi-Fi data traffic. Transition to rich contents particularly voice and multimedia contents has underlined the essence of quality of service (QoS) in communication networks particularly in wireless networks.

In Wi-Fi networks, QoS refers to a set of policies in order to utilize network resources and provide prioritization for services. For example, cellular traffic offloading or video calls should have priority over bulk download in the network in order to result in greater user satisfaction. However, the end user does not judge the network elements solely; user may consider overall system performance, quality of the content, price of the service and the ease of use as factors for service assessment [2]. In order to clarify viewpoints of different actors, international telecommunication union (ITU) recommendations have divided QoS to *(i)* QoS requirements of user *(ii)* QoS planned or offered by the provider *(iii)* QoS achieved or delivered by the provider *(iv)* QoS perceived or experienced by the user.

Numerous research has attempted to improve multimedia QoS in wireless networks so that they have focused in context of individual architecture components particularly in the physical layer enhancement and algorithms. In addition to IEEE 802.11e QoS amendment [3], many research projects have attempted to enhance quality of service in medium access control (MAC) or physical layer of 802.11 e.g. enhancement of distributed coordination function (EDCF) [4], improving QoS performance using algorithms such as enhanced opportunistic auto rate (OAR) [5] or a carrier sense multiple access (CSMA)-based MAC protocol for providing hard QoS guarantees [6].

However, the existing 802.11 quality of service amendments and algorithms do not ensure carrier-grade quality for emerging applications. Indeed, Wi-Fi requires an extensive analysis to find out variables that influence overall Wi-Fi quality in smart infrastructure regarding application requirements and user expectations.

This paper presents the concept of cumulative parameter monitoring and analysis in order to improve overall experience in Wi-Fi. Indeed, this paper considers security and privacy in addition to generic network performance parameters in order to ensure user acceptability regarding novel services in Wi-Fi networks. The proposed concept considers Wi-Fi performance parameters with respect to various services in order to facilitate quality improvement actions in smart infrastructure. As a result, the proposed concept can establish a basis to estimate user experience objectively rather than out of box subjective evaluation.

The rest of the paper is as follows: background and related works in wireless networks particularly in Wi-Fi networks appear in Section II. Wi-Fi service description including the existing and future status of Wi-Fi services appears in Section III. The network monitoring parameters description including individual generic parameters and Wi-Fi specific parameter appear in Section IV. Requirements of future services appear in Section V, while Section VII presents the cumulative network parameters monitoring. Finally, Section VIII concludes cumulative network parameters monitoring concept that follows up by future research plan.

II. Background and Related Work

To deal with user satisfaction, the term quality of service was originally defined in 1994 in the field of telecommunication in international telecommunication union (ITU) recommendation [7] and has extended to IP network. According to the ITU recommendation E.802 [8], the QoS is defined as "*the collective effect of service performances, which determine the degree of satisfaction of a user of the service.*" Now, there are several standardization and recommendation documents related to the quality of service by ETSI [9], IEEE [3], 3GPP [10] and IETF [11].

Long before Wi-Fi, quality of service concept introduced in cellular networks, while provisioning higher system capacity with lower cost. The call admission control (CAC) was one of the fundamental mechanisms used for quality of service provisioning in the cellular network in order to avoid network congestion and service degradation. In the CAC mechanism, an accepted call may have to hand off to another cell and consequently, the call may not be able to obtain a channel in the new cell, which will lead to call dropping. Hence, hand off calls normally assigned priority over new calls because users are more sensitive to call dropping than new call blocking [12], [13]

Traditional Wi-Fi local area networks (WLAN) can be interpreted as a wireless version of Ethernet, which provides best effort mechanism. In this kind of networks, all connected devices have equal access so that exceeded network traffic will affect all the devices regardless of application type. Hence, application prioritization similar to cellular accepted call prioritization has used in Wi-Fi networks in order to improve the QoS in the best effort networks. Besides, numerous research has attempted to improve QoS of 802.11 technology, particularly algorithms and MAC layer improvements; some of the previous efforts were standardized in 802.11e amendment [3], which published in 2005.

However, novel services and applications are emerging over the Wi-Fi networks in various domains such as smart homes, in-vehicle connectivity, enterprise or smart cities. New applications have changed the type of Wi-Fi traffic from delay-tolerant to real-time data streams. For example, live streaming TV, online games, VoIP and many IoT applications require a real-time with zero delay communication.

Service providers deliver Internet to the end-users and are obliged to provide carrier-grade quality, but delivering only carrier-grade Internet to the Internet gateway may not result in user satisfaction. Hence, service providers should study user expectations and monitor performance and non-performance parameters in order to be able to improve the user satisfaction, while end-users expect carrier-grade end-to-end quality for a set of different applications over Wi-Fi. Therefore, quality of service divided to different viewpoints in order to clarify roles and expectation of different actors. In this respect, the QoS requirements of a user refer to the level of user quality expectation for a specific service, which may be presented in descriptive and non-technical terms. The QoS requirements may be influenced by different factors such as criticality of a service, user lifestyle, and context of service usage. The QoS offered by the service provider refers to the planning of particular service quality to be delivered to users in the form of service level agreement (SLA). The QoS achieved refers to the level of actual quality achieved or delivered to the user. Finally, QoS perceived refers to the level of quality that users believe they experienced and usually called quality of experience (QoE). The QoE is generally assessed by user surveys and feedback [14].

III. Wi-Fi Services: Today and Tomorrow

The role of Wi-Fi has transformed from simple connectivity method to a strategic role in providing connectivity to various types of devices. Wi-Fi enables various value-added services, such as indoor positioning, proximity marketing and advertising for different businesses. Meanwhile, concept of function virtualization and separation of software and hardware functions will impact Wi-Fi ecosystem by enabling service agility approach.

The accelerated acquisition of smart-phones and tablets has significantly increased the demand for video streaming everywhere. The concept of TV everywhere provides freedom to watch on-demand or live high definition contents on mobile devices whenever and wherever the user desires. According to the Cisco [15] reports 79% of mobile data traffic will be video by 2022. Apart from that, video on demand service has specific requirements based on the encoding and the rate of the video stream. For example, certain video formats with low-compression encoding and high rate of video stream require higher bandwidth or wireless airtime to be streamed in the target device. Meantime, devices at the edge of basic service set (BSS) can consume most of the wireless airtime so that other devices receive a small share of wireless airtime for the video on demand streaming. As a result, clients may experience poor video quality regardless of their excellent signal strength.

The home and building security systems including fire alarm system are now using wireless technology. Now, most of the home security and alarm systems support Wi-Fi in order to provide remote monitoring and management as well as notify authorities in case of emergency. Hence, users expect their security and alarm systems to be highly available and have prioritized over other connected devices to the Wi-Fi network.

On the other hand, new concepts such as ehealth consider wireless technologies as an enabler for their innovative services and use cases. For example, using wireless technologies, telesurgery, teleconsultation, telediagnosis and telemonitoring can have considerable uptake among the consumers and health professionals. However, using wireless technologies in ehealth applications may impose security and privacy concerns, which significantly affect user acceptability. In addition, ehealth applications demand highly reliable wireless communication with near zero delay, jitter and information loss.

The virtual reality (VR) and augmented reality (AR) is starting to uptake in consumer market as well as other professional domains. The VR and AR technology have driven by applications such as immersive gaming, virtual maritime and aviation training, medical or surgical training, furniture or clothes comparison in retail shopping, tourism, and informative graphics in smart infrastructure. However, VR and AR technologies demand higher bandwidth with near-zero delay in order to provide real-time and high resolutions content to the users.

The existing services are going to demand carrier-grade quality in form of higher bandwidth, near-zero delay, jitter and information loss in the Wi-Fi networks as a an access network, while upcoming services have additional requirements such as security, privacy and reliability.

IV. Quality Monitoring

With the increase of demanding services over Wi-Fi networks, improving Wi-Fi quality for critical services is extremely important for user adoption. Hence, continuous monitoring is an essential approach to examine performance and non-performance parameters in order to find out causes of quality degradation.

However, monitoring individual performance parameter or a subset of parameters may not provide complete insight into user dissatisfaction, while user experience is affected by various factors rather than solely performance parameters. Indeed, evaluating user experience is totally related to the user requirements, which define user expectations of a service in terms of performance, security and privacy measures.

Although users have distinct requirements, many entities defined a set of generic performance parameters for all communication networks. According to ITU-T recommendation G1010 [16], there are three key performance parameters that affect user comprising delay, jitter and information loss. Definition of generic performance monitoring factors may impose limitations in recognition of causes of quality degradation or poor user experience.

Generally, delay can be defined as the time of service establishment from initial request to receiving requested information [16]. There are various forms of delay in a network including client request delay, server response delay, network elements processing and routing delays. Delay in each form can affect communication performance and particularly user perception of a service quality. For example, the delay can significantly affect ehealth applications such as telesurgery, telemonitoring [17] or tactile Internet applications such as augmented reality or machine control operations, which have zero delay requirement [2]. Nevertheless, Wi-Fi is the weakest link in an end-to-end communication that can cause a high delay in the network. For example, Pei et al. [18] presented that airtime utilization and received signal strength indicator (RSSI) can cause a significant delay in the Wi-Fi network so that minimizing high airtime utilization reduced access point (AP) largest delay from 250ms to 50ms and relocating AP reduced the median delay from 50ms to 10ms. Although, high channel utilization, interference, signal strength and distance can cause a significant delay in a wireless communication, only an end-to-end delay monitoring cannot demonstrate the cause of delay in a communication.

Hence, a series of experiments performed to identify web browsing page load time (PLT) factors. results indicated that DNS lookup process caused delays more than 200 milliseconds with even national name servers. In these cases, wireless performance parameters and round trip time could not identify the cause of delay. Indeed, solo evaluation of end-to-end delay may result in negative user perception about quality of Internet service rather than specific communication components that degraded service quality.

Delay variation of received packets generally called jitter [16], which may vary due to link congestion, improper queuing, or interference in the wireless network. Basically, applications that are delay-sensitive cannot tolerate jitter as well. As a result, application that cannot tolerate jitter attempt to remove jitter by means of buffering, which may add additional fixed delay. The buffers are implemented in various segments of a network including client, server, Wi-Fi access points, routing and switching devices. Access points with a large buffer can cause jitter in the communication link. For example, the more clients connect to the AP, the AP tends to increase the size of buffers and queue more packets. Indeed, the oversized buffers can cause jitter and reduce the Wi-Fi throughput because packets buffered too long, rather than dropping packets. This behavior is known as bufferbloat and it can significantly affect network throughput in Wi-Fi access points [19]. Although bufferbloat causes jitter in Wi-Fi network, only an end-to-end jitter monitoring cannot demonstrate which part of communication link causes jitter.

Information loss affects data transmission in form of unrecoverable bit errors or packet loss as well as any media encoding degradation [16]. The information loss can implicitly cause delay and jitter because of retransmission of packets. Although 802.11 physical layer uses error detection and correction mechanisms such as forward error correction (FEC) or low-density parity check (LDPC) in Wi-Fi, packet loss rate can be high. Packet loss can be caused by head-on collisions, hidden nodes, interference, rate control algorithms or airtime. For example, Murray et al. [20] presented that possibility of information loss of frames that spend more time in the air because of low data rate is higher than those frames that transmitted at high data rates. in aditiion, clients connected at low data rates in the Wi-Fi network prone to higher packet loss and consequently higher retransmission rates so that they consume large airtime of the wireless medium. However, packet loss may not solely cause by interference, whereas packet loss can be caused by protocol mismatch, network device capacity limit or link congestion. Indeed, monitoring of information loss cannot represent causes of quality degradation, whereas information loss can be caused by various elements in the network. Therefore, users may perceive that the quality of Internet is degraded rather than quality of specific network segment.

The amount of data that clients transmit and receive in a specific time is the most widely used operational parameter

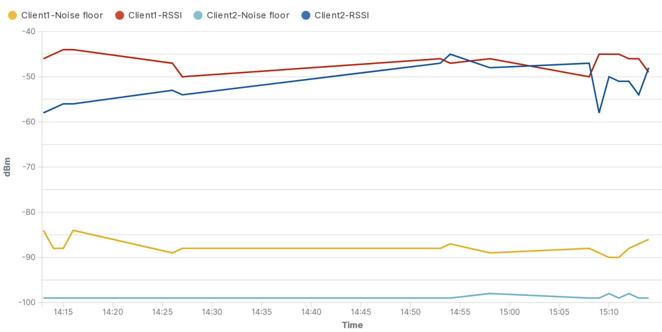

Fig. 1. RSSI and noise floor of two mobile phones at the same location.

as a network performance indicator. The video streaming, online gaming or virtual reality require high throughput connectivity. Traditionally the average downlink or maximum throughput has been used to evaluate network performance. The average or maximum throughput is not informative parameter in wireless links because throughput fluctuation can happen due to interference or path loss. Casas et, al. [21] presented that throughput fluctuation can significantly affect the user experience of interactive applications such as web browsing. However, high throughput communication cannot solely demonstrate acceptable service quality, whereas Wi-Fi throughput can be high, but the retransmission rate can be significant as well. An experiment performed to identify video conference quality degradation on Wi-Fi and the captured frames indicated almost 50% retransmition over an 802.11ac link with 468 Mbps maximum throughput. Indeed, throughput is a complementary parameter for quality monitoring rather than a standalone parameter in Wi-Fi networks. Hence, the average or maximum throughput can be high, when user may experience poor service quality due to throughput fluctuation or high retransmissions.

In wireless communication, signal strength has been used to demonstrate quality of wireless link and coverage. It is common that received signal strength indicator (RSSI) value used as a signal strength such that devices with RSSI lower than a specific value determined to experience poor link quality. For example, the minimum recommended RSSI for voice and streaming video is -67 dBm and minimum recommended RSSI for only connecting to the network would be -80 dBm. Although RSSI has been commonly used for indicating wireless link quality, the IEEE 802.11 standard recommends vendors to supply RSSI as a one-byte field relative to received signal strength (RSS) in the physical layer so that radio devices can use RSSI for clear channel assessment (CCA), carrier sense, and handover management. The IEEE 802.11 standard does not indicate how vendors should relate RSSI to RSS so that different wireless devices report different RSSI values [22]. In this respect, Lui et al. [23] performed an experiment to compare RSSI of 17 different Wi-Fi devices within 0.3 to 35m distance from access point. They presented that individual Wi-Fi cards reported different RSSI value in an indoor test, such that Wi-Fi cards reported as many as 30 dBm average RSSI difference at the same location. As a result, RSSI cannot be accounted as a universal parameter for Wi-Fi QoS monitoring, while each device reports different RSSI value in the same location. However, antenna design factors, antenna polarization and gain, hardware design, device driver and particularly noise floor or sensitivity of a device affect the quality of the wireless link. Testbed experiments comprising Android tablets and mobile phones performed to compare sensitivity and RSSI of different devices in a same location. Figure 1 illustrates information about noise floor and RSSI of last received frame of two different mobile phones in the same location. The noise floor difference in two devices was as many as 10 dBm so that difference of SNR of two devices was at leas 10 dB . Although users see acceptable signal strength indicator on a Wi-Fi device, user may experience quality degradation due to characteristics of wireless interface of device. Hence, a cumulative parameter monitoring will be an optimal solution for precise analysis of QoS and consequent QoS improvement actions.

V. Requirements of Future Services

The VoIP, video streaming, cyber-physical and ehealth services are in a particular interest and Wi-Fi technology play an important role in the uptake of these services.

Users expect to stream video everywhere at any time so that they expect high throughput Wi-Fi connectivity everywhere at home or buildings. However, providing full coverage with high throughput everywhere is challenging, which requires taking advantage of remotely managed Wi-Fi access points rather. Delay and jitter may not be a challenge in the on-demand video streaming, while client's application use buffering to overcome delay and jitter. Video streaming has not a significant security risk, whereas lack of privacy consideration can reveal user's habits.

The alarm and security systems are going to use wireless technology in order to reduce cost and improve efficiency. However, using wireless technology for alarm and security systems that require high availability is challenging, because existing Wi-Fi technology provides best effort communication. These systems require reserved bandwidth with zero information loss for its critical communication in case of an emergency such as smoke detection or fire alarm warnings. In addition, security and privacy consideration are necessary, while hackers can breach into homes and buildings by sniffing wireless signals and compromising communication of alarm and security systems.

The ehealth services pervasively use wireless technologies in order to provide health services efficiently. For example, health centres can use implantable electronic devices to monitor patients' heart failure, which will optimize health care resource usage [24], [25]. However, security and privacy risks hinder users to adopt ehealth services over wireless technologies. In case of implantable devices, patients and health professionals expect reserved bandwidth with zero delay and information loss wireless connectivity as well ass high

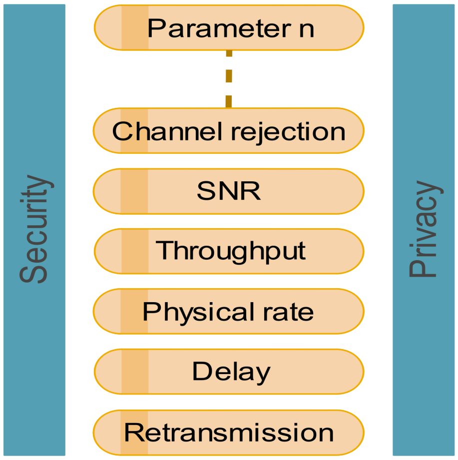

Fig. 2. Cumulative network parameters model.

security and privacy measures. In case of teleconsultation or telediagnosis, patients and health professionals expect a high throughput with zero delay, jitter and information loss Wi-Fi connectivity as well as high security and privacy measures.

Users expect a different set of requirements for each service so that it is not sufficient to evaluate quality based on only a subset of performance parameters. Hence, cumulative network parameters monitoring and analysis can meet the expectation of large variety of services with a different set of requirements.

VI. Case Study

A series of experiments performed in order to investigate performance parameters in Wi-Fi networks. In experiments, 5 Android tablets with IEEE 802.11n wireless interface connected to a commodity access point (AP). Tablets were placed near AP in the first series of experiments and placed sparsely in the second series of experiments. In each experiment, different applications including web browsing, YouTube streaming, Skype and heavy TCP download executed while network parameters collected on Wi-Fi AP. In each second, over 200 AP parameters and over 20 parameters per device collected in a database for further analyses. Analysis indicated that various parameters have high information gain such that these parameters can be used to estimate quality for different applications. Part of the analysis will be presented in the following section.

VII. Cumulative Monitoring of Performance Parameters

The monitoring subset of performance parameters can be employed to identify specific problem, but it cannot guarantee that service is acceptable for users after solving the problem. Hence, a cumulative network parameters monitoring is an optimal solution for granular quality analysis and consequent improvement actions. The generic performance parameters including delay, jitter, information loss and throughput provide overlapped information e.g. information loss may implicitly affect delay, jitter and throughput in any type of network. By contrast, signal to noise ratio (SNR) or RSSI is a unique feature of wireless networks. These performance parameters can provide extensive information when they are assessed together. Wi-Fi access points provide a set of wireless parameters such as number of bytes sent and received, RSSI of last frame received, noise level, frame check sequence (FCS) errors, number of retransmissions, number of exhausted retransmissions, TX/RX physical rate, transmission error, number of RTS/CTS frames, number of good and bad packets, TX channel rejection and encryption key size.

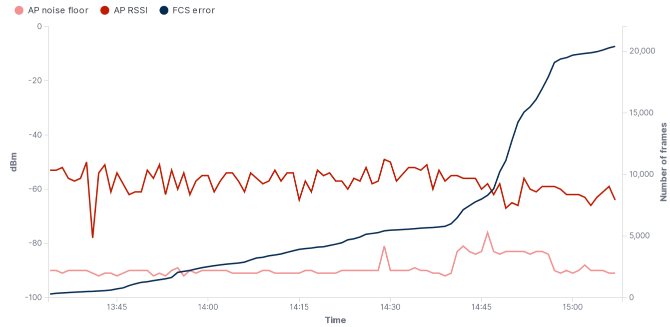

Fig. 3. Detect interference by monitoring noise level and number of FCS errors.

A first derivation of number of bytes sent and received results throughput of access point and individual client which can monitor performance of the network. Monitoring transmission errors along with number of RTS/CTS frame, frame check sequence (FCS) error and noise level can identify interference duration and intervals. Figure 3 illustrates access point noise level, RSSI and FCS errors during interference such that access point noise level and FCS errors increased considerably for near 15 minutes. Monitoring TX channel rejection can identify duration and interval of adjacent channel interference in Wi-Fi network. Number of beacon transmitted in a period can identify channel saturation by monitoring beacon transmission jitter.

Users do not evaluate services based on performance criteria solely so that perceived quality is not a mere performance evaluation. The ever-increasing security and privacy breaches in the cyber-physical and wireless systems is becoming a major concern, whilst more critical services are going to be presented through wireless technologies. Because Wi-Fi security developments and privacy considerations are not mature enough, security and privacy concerns are going to hinder user adoption and acceptability of new services even for non-technical users. A study presented that security measures knowledge improves Wi-Fi adoption for critical services among the users [26]. Hence, parameters such as authentication method, authorization method, encryption method or encryption key size are additional QoS monitoring parameters that can be used to evaluate quality of security and privacy measures in Wi-Fi network. In addition, parameters such as number of decryption failure in Wi-Fi clients can indicate the impact of security and privacy measures on the quality of service. Indeed, incorporating security and privacy in quality monitoring and analysis can help to improve service acceptability by users.

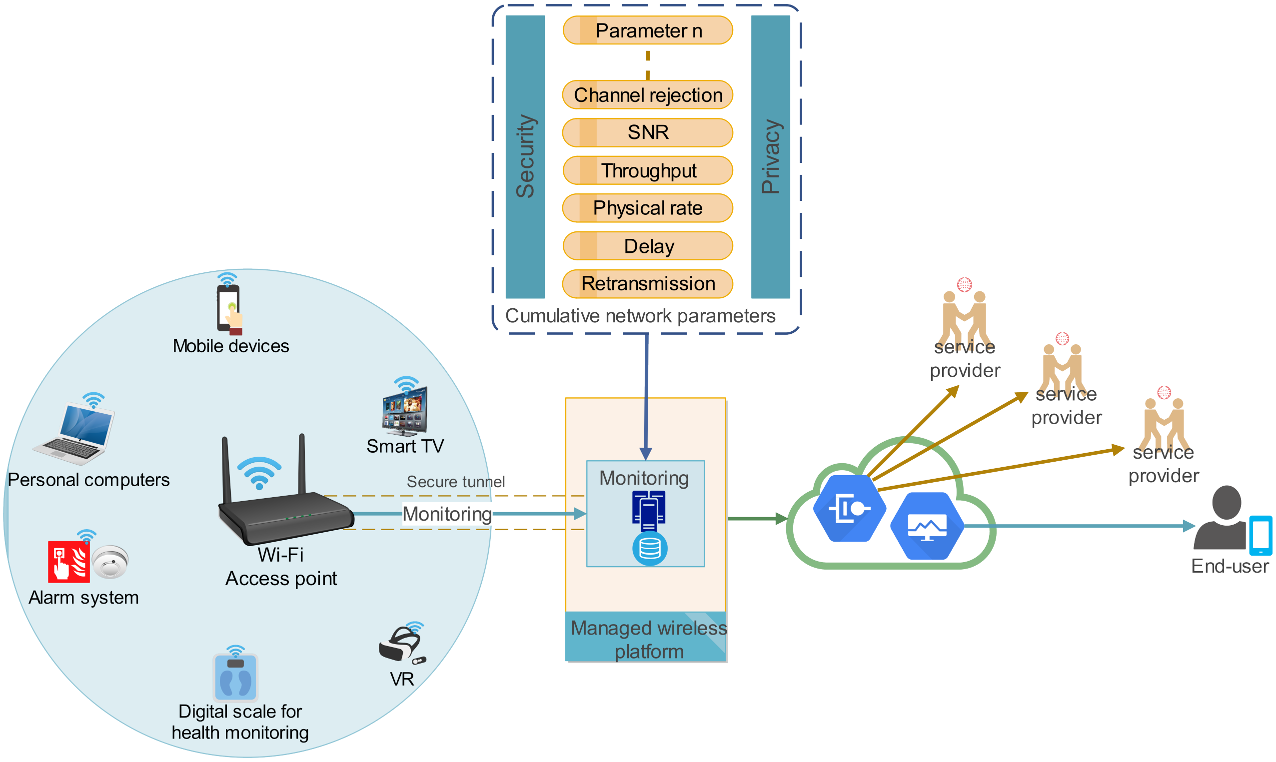

Fig. 4. Cumulative network parameters monitoring and analysis of home Wi-Fi use case.

The existing QoS improvements in Wi-Fi access points focus on service prioritization such that well-known services are identified and prioritized over all other traffic. Although this approach improves QoS for specific services such as voice and video calls, most of the voice and video traffic detected as background traffic. Hence, cumulative network parameters monitoring will be an optimal solution in order to identify quality degradation and consequently improve quality. This paper presents a cumulative network parameters monitoring, in which considers as many as parameters that can help to precisely monitor quality of Wi-Fi. In this model, security and privacy parameters alongside performance parameters ensure that proper security and privacy measures will improve acceptability and uptake of novel wireless services in smart infrastructure. Figure 2 illustrates proposed cumulative network parameters model consists of security and privacy in addition to performance parameters. The model indicates that a set of parameters should be monitored together in order to ensure infrastructure wide quality.

Delay in a communication can occur in various segments of a communication link such as Wi-Fi network delay, server-side delay or intermediate routing or switching delay. Packet loss and subsequent retransmissions in wireless medium can cause delay so that cumulative network parameter monitoring can correlate packet loss and delay to identify root cause of delay. Likewise, low-level of signal strength and high number of retransmission cause delay and can be identified by level of SNR. Figure 4 illustrates cumulative network parameters monitoring for home Wi-Fi use case such that different service providers can monitor their services through monitoring and management cloud platform API. Remote monitoring and management platform enables service providers to support customers efficiently using historical.

The cumulative network parameters monitoring can provide sufficient information in order to estimate the quality of user experience through performance parameters and security and privacy measures. This will pave the way to implement a new approach to measure the quality of user experience objectively.

VIII. Conclusion

The Wi-Fi connectivity is a preferred wireless technology at homes and buildings. Pervasive services with multimedia contents have underlined the monitoring and improvement of quality of service in the limited wireless medium. This paper presented the concept of cumulative network parameters monitoring and analysis to improve overall quality of Wi-Fi. The proposed concept considers security and privacy measures alongside a set of various performance parameters in order to provide a baseline for objective assessment of acceptability of novel services in smart infrastructure. The proposed concept enables service providers to obtain insight into quality of Wi-Fi networks in smart infrastructure and accordingly ensure carrier-grade quality for novel services.

Although there are generic performance parameters, the wireless performance parameters have not been well studied. In a follow-up research, the correlation of network parameters with user experience will be assessed and QoE will be estimated using machine learning in Wi-Fi networks. In addition, security, privacy and performance parameters reported by Wi-Fi access points will be studied in order to detect security anomalies and accordingly improve security and privacy in smart infrastructure.

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