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Adaptive Wi-Fi offloading schemes in heterogeneous networks, the survey

Ruliyanta[1, 2], Mohd Riduan Ahmad[2], Azmi Awang Md Isa[2]
[1]Department of Engineering and Science, Universitas Nasional, Jakarta, Indonesia
[2]Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer, Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia

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ABSTRACT

At present, the need for data traffic is experiencing tremendous growth. The growth of smartphones technology offers new applications. On the other hand, the growth in cellular network access infrastructure has not been able to keep up with the increasing demand for data package services. For this reason, Wi-Fi offloading is needed, namely cellular users, using Wi-Fi access for their data needs. In 2016, global data communication traffic growth reached 63%. Many researchers have proposed the adaptive wireless fidelity (Wi-Fi) offloading (AAWO) algorithm to transfer data on heterogeneous networks. In this study, the proposed adaptive incentive scheme is classified, to obtain an adaptive scheme based on cost, energy, service quality, and others. From the survey results shown, there is no proposed adaptive algorithm based on the quality of experience (QoE). This provides an opportunity for further research where the Wi-Fi offloading scheme uses the perspective user or user experient options. In addition, open research uses artificial intelligence and machine learning methods as adaptive methods.

Corresponding Author:

Mohd Riduan Ahmad
Centre for Telecommunication Research and Innovation (CeTRI)
Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Street of Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Email: riduan@utem.edu.my

1. INTRODUCTION

Currently, the growth rate for cellular data traffic is very fast. Likewise, the growth of smartphones with various applications that spoil users with various new applications. In 2016, global data traffic growth reached 63%, with the highest growth occurring in the African continent and the Middle East, reaching up to 96% [1]. The second-largest growth was the Asia Pacific which reached 71%. According to Cisco, Indonesia is the country with the highest data traffic growth in the world, reaching 143%, followed by China at 86% and India with 76%. Based on the compound annual growth rate (CAGR), Cisco forecasts, mobile network data traffic to increase by 49 exabytes, a 7-fold growth. Since the growth in data traffic provided by cellular operators cannot meet the speed of data traffic demand growth, the Wi-Fi offloading is proposed, this scheme is a data transmission technology that is carried out over cellular networks and transferred through other types of radio access technologies (RAT) such as wireless fidelity (Wi-Fi). Wi-Fi has high data transfer and better energy efficiency than cellular networks [2]–[5]. To combat the explosion in cellular data traffic, it is simpler to increase the number of base transceiver station (BTS) so that the cell size becomes smaller. This solution requires a very large capital expenditure (CAPEX) and operational costs (OPEX). Another solution is to take advantage of usage-based pricing plans. This limitation is incompatible with the future traffic data structure which is independent of usage and is heterogeneous [6]-[8].

There are two technology platforms that support at this time. The first is the cellular radio technology and the second is the Wi-Fi standard released by 3rd generation partnership project (3GPP). Figure 1 illustrates the development and convergence road map leading to inter-cellular/Wi-Fi integration.

The ultimate solution to meeting the need for explosive bandwidth demand has long been to utilize the Wi-Fi networks [9], [10]. With the development of Wi-Fi standards, it is expected that the connection speed for the Wi-Fi Offloading process can be improved as well. Cisco forecast, globally by 2023. In Cisco's predictions, the number of Wi-Fi in 2023 will reach up to 628 million, wherein 2018 the number is only 169 million, this has increased by more than four times. The most significant growth is in the Asia Pacific where the increase will reach 46 percent where growth will occur in public areas and in housing. The most common model is the residential Wi-Fi sharing.

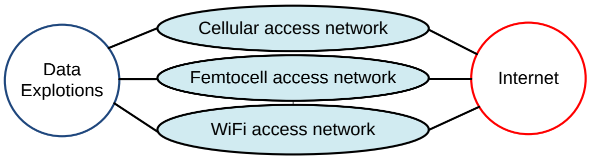

Figure 1. Radio access technology on heterogeneous networks

The use of Hotspot 2.0 on a Wi-Fi gateway will immediately switch to a higher speed by adopting the newest IEEE Wi-Fi standard. In 2020-2023 Wi-Fi 6 hotspots will increase rapidly by 13 times so that the world's total Wi-Fi will increase to 11% [11]. To improve service, IEEE 802.11 ac provides premium service for high-speed Wi-Fi on the 5 GHz frequency [12]. Another method to improve Wi-Fi performance is to upgrade the existing antenna with a microstrip antenna [13], [14]. TOPSIS and VIKOR algorithms were investigated in the Wi-Fi radio spectrum to address handoff failures [15].

To accommodate the growing data traffic needs that can be experienced by cellular operators, users are offered to the Wi-Fi network. However, the Wi-Fi offloading scheme previously proposed is still focused on reducing cellular data usage, without regard to the service quality requirements QoS of the application being used [5], [16]–[21]. Intending to provide an appropriate tradeoff between billing and the quality of service (QoS) provided, with a measure of data transfer speed, they propose delay-aware Wi-Fi Offloading and network selection (DAWN) algorithm. Analytically, they look for the most appropriate conditions to determine the proper parameters for the size of the time delay and file size. Finally used the DAWN monotone algorithm, which can solve Wi-Fi offloading problems in general and a low level of computational complexity [5]. The Wi-Fi offloading roadmap is shown in Figure 2.

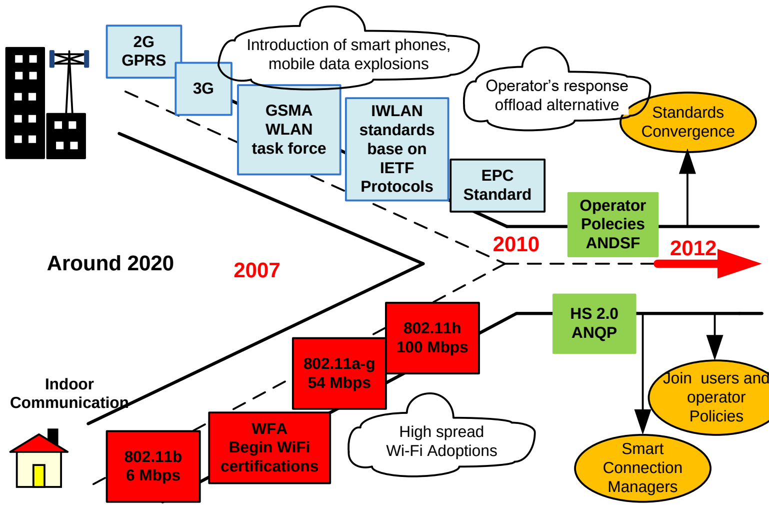

Figure 2. Roadmap Wi-Fi offloading

In Wi-Fi user's utilization patterns, it is examined in two groups of coverage, including temporal or spatial coverage [7]. The measurement of Wi-Fi network performance will be considered based on QoS, including rate, end to end throughput and packet loss. The size of user behaviour will find out how long the user is doing Wi-Fi offloading, besides what type of application is used and the quality of experience (QoE) of the Wi-Fi network being used. The main purpose of this research is to survey the use of adaptive schemes on Wi-Fi offloading technology. Researchers are looking for more adaptive methods that are more suitable for further development. Thus, it can be determined that different intensities can become prospects for next research.

2. BASIC INCENTIVE

2.1. Wi-Fi offloading

Mobile data offloading is often known as Wi-Fi offloading. That is the process by which a cellular subscriber when communicating with data, switches to a Wi-Fi network. This technique continues to be developed by researchers to improve their performance [5], [22]–[24].

2.2. Requirements of 5G systems

The main goal of fifth generations (5G) technology is different from previous technologies that prioritize high data speeds. Compared to previous cellular technologies, 5G will have cheaper costs, lower latency, and much more efficient use of battery energy [22]–[25]. Of course, 5G can also be used on heterogeneous networks. In the 5G system, it will ensure that users get the best QoS and customer satisfaction anywhere by utilizing air interface interfaces such as Wi-Fi, femtocells, and microcell whereas previous cellular systems still use macro-cells [6], [7], [19], [21], [25]–[29]. To accommodate the need for 5G, several studies have been conducted. To reduce the time delay, which is up to 1 ms, cloud-based technology is used. The first is proposed as network function virtualization (NFV) while next propose is software-defined network (SDN). To increase data rates, commonly proposed solutions are the multiple input, multiple output (MIMO) technique and millimeter waves (mm waves).

To increase the signal density received by the user equipment, the solution is to reduce the distance between the base station and the mobile device. There are two ways to do this, the first is to increase the number of BTS to make the cell size smaller. This first option has constraints because it increases the CAPEX and OPEX. The second method is to use some radio access technology, the problem is how to solve interference. Finding effective access to divert cellular networks to other radio access technologies is the third challenge. The next challenge is managing and coordinating the existing radio access network so that it can support heterogeneous network mobility while keep providing user experience and QoS.

2.3. Network selection scheme

When we refer 5G, there is currently no single radio access technology. Capable of simultaneously delivering to low-cost services, low latency, low energy consumption, high bandwidth, and high data throughput to many mobile users. The smart terminal mechanism by which the radio interface can select the appropriate parameters.

2.3.1. To select a network

Network selection scheme (NSS) submits the user equipment to select radio access technology RAT, which is available both Wi-Fi and cellular networks. The most traditional RAT selection mechanism used Receive Signal Strength (RSS), while the speed and data density are negligible. In determining RSS, the density signal to interference and noise ratio (SINR) is used as a consideration in radio network occupation. Table 1 provides the 3 factors most used to determine NSS.

Table 1. Considerations for NSS

Category	Considerations
Device status	Application type, Battery life, physical speed, Network selection hystory
Channel status	Radio channel quality, Physical obstructions, Relative position
Systems status	Energy efficiency, Average throughput, Response time, QoS, Port Blocking, Backhoul Capasity

In his research [30]-[33], implemented "Wi-Fi First" which is a network selection scheme (NSS) based on received signal strength (RSS). When users of an long-term evolution (LTE) network are switched to a Wi-Fi network, the capacity of the LTE network is only reduced by 2.75%. However, the average quality of the LTE user experience improved by 100%.

2.3.2. Handover strategy

Handover has two types, namely vertical handover (VHO) and horizontal handover (HHO) [34], [35]. In HHO, the work system adheres to the highest RSS value, while in VHO it optimizes the resources between radio access networks. For this reason, researchers are currently making efforts to optimize the performance of heterogeneous networks [30], [36]. They combine the concept of genetic zone routing protocol (GZRP) with the VHO Algorithm to be applied to BTS networks. The proposed algorithm can significantly increase the throughput and reduce handover delay. Quang and Ho-Sy [37], optimizes Wi-Fi signal reception by using the Maximum convergence algorithm in the Indoor area.

2.3.3. Access network selection algorithm

The 3GPP has determined a special algorithm for equipment users to discover non-cellular networks around it in access network discovery and selection function (ANDSF). ANDSF will control the handover process that occurs [7], [8], [23], [38]–[40]. ANDSF is an important research topic to improve system performance.

In 3GPP Release 10, there is a re-configuration of the inter-system mobility system and the routing policy on ANDSF. With this flexibility the EU can perform the most suitable network access restoration. In [39], they propose the incorporation of network event reporting function (NERF) at the access network level and an upgrade to ANDSF. With this Merger, information on the characteristics of network access will be obtained and used as input which is used as an input for the multi-attribute decision making (MADM) module.

3. CLASSIFICATION ACCORDING TO INCENTIVE OF WI-FI OFFLOADING

According to Wi-Fi offloading is divided into 2 groups, namely delayed and non-delayed offloading [7]. The classification is given in Figure 3. The classification is distinguished according to the basic class, modeling method, control mechanism, and infrastructure.

3.1. Capacity

There have been many efforts to increase Wi-Fi Offloading capacity. Researchers propose improvement efforts to increase the capacity of LTE and heterogeneous networks, as shown in Table 2. The classification is distinguished according to the basic class, modeling method, control mechanism, and infrastructure.

3.1.1. Non-delayed offloading

The existing smartphones still use traditional ANDSF. Thus, the algorithm used is still based on the strongest signal. If the RSS from the EU entering the Wi-Fi area is non-zero in density, offloading will occur. If the RSS is zero, then the data transfer is carried out using a cellular network [7]. Several studies were conducted to increase the total amount of data transferred [41], it is proposed that the method of integrating mobile integration gateway (MIG) with the algorithm on the Network switch subsystem and it is based on channel quality [42] proposed a different scheme. With dynamic offloading technique, the mobile operator uses a policy server to obtain user behavior.

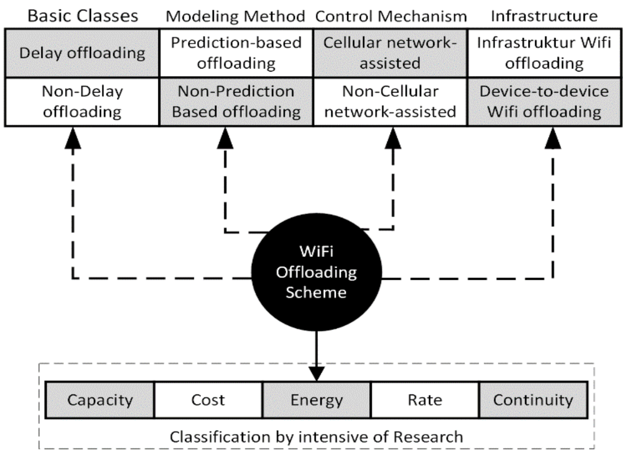

Figure 3. The Classifications of Wi-Fi offloading [7]

Table 2. Some incentives by increasing capacity

Incentive	Capacity	
Sunject	Amount of Total Mobile data traffic being offloaded	Throughput per user (of LTE network/Heterogeneous Network)
Non-delaed offloaing	Network selection Scheme Deploying strategy of Wi-Fi Network	Network selection Scheme Deploying strategy of Wi-Fi Network Optimization Problem in modeling
Delayed offloading	Tradeoff between Delay and Amount User's Trace/Real-Time-Measurement Base Network selection Scheme	Tradeoff between Delay and Throughtput

The "Wi-Fi First" algorithm is proposed to increase the throughput [11], [31]. This method is like the "on the spot" offloading method. in the experiment carried out with the LTE channel model, the Wi-Fi channel, and building contour height modeling.

3.1.2. Delayed Wi-Fi offloading

Wi-Fi offloading allows delayed methods. Data transfer can be done via Wi-Fi when getting a signal. When the Wi-Fi signal is lost, the transfer process will stop and wait until it is back in the Wi-Fi range. This delaying process has a delay tolerance. To meet user satisfaction, a special scheme needs to be implemented to overcome the delay in the amount of unloading. Cheng *et al*. [43] proposed an analytical relationship between offloading effectiveness and average service delay [7], [43], [44]. To investigate how long the user must wait for offloading and how much data must be uploaded, [44] propose a utility function to calculate volume of data traffic being unloaded and QoS.

3.2. Cost

An investigation is needed to determine the benefits of Wi-Fi offloading. The operator's perspective is usually the opposite of the User's perspective. In terms of operators, to increase cellular network capacity and meet traffic demands from users, operators do not necessarily increase the number of BTS, this is related to increasing CAPEX and OPEX [7] have modeled a relationship between one operator and user based on a two-stage sequential game scenario.

The numerical result is that the increases ranged from 21% to 152% in operator revenue, and from 73% to 319% in user surplus. Offloading will be well received by users and operators if it is economically useful. Therefore, it is necessary to research to determine the advantages of Wi-Fi offloading from the perspective of both the operator and the user. A study calculates the operator unloading savings by empirical calculations [45]. They propose a method to get maximum income by numerical calculation. From the user perspective, expect the costs incurred by the quality of throughput, and delay the tradeoff of different applications. Another research proposes an offloading system that is cost aware. You do this by using adaptive bandwidth management through user-empowerment (AMUSE), as shown in Figure 4 [46].

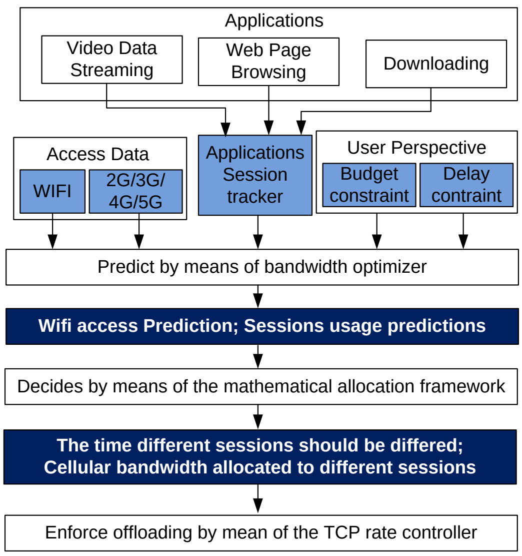

Figure 4. The main idea of AMUSE mechanism

From the user perspective, expect the costs incurred by the quality of throughput, and delay the tradeoff of different applications. Another research proposes an offloading system that is cost aware. You do this by using Adaptive bandwidth Management through User-Empowerment (AMUSE), as shown in Figure 4 [46]. The mechanism of this offloading system is on the user side, with the target giving the user the option to intelligently choose the data traffic offloading based on the preference settings made by the previous user. The method uses the utility maximization algorithm to calculate the tradeoff-delay of user throughput and cellular budget constraints.

3.3. Energy

Green energy is one of the researchers' concerns currently. The researchers formulated a mathematical model which is a function of bit rate against load to measure energy consumption. According to [27] Energy consumption is given by:

$$E = \frac{C}{R+D} + (M - 1000)A \quad (1)$$

where: *E*=are the energy consumed (Joules),
R=are the bit rate (Kbps),
M=are the amount of load,
whereas *A*, *C*, *D* are constant parameters that vary with Wi-Fi and cellular networks.

To increase power density, a collaboration with a third party is proposed, the problem is that the energy consumption of BS is directly proportional to the offload performance of data traffic. The higher the data is transmitted, the greater the energy consumption. By leveraging existing Wi-Fi mesh networks, Apostolaras *et al*. [8] proposed the method. However, the end result of the user operator is not clear.

3.4. Rate

The concept of rate describes the average performance when completing data offload measured in QoS. Several factors used to determine the transmission rate are radio network access, delay, jitters, and congestion. However, some researchers measure it in terms of throughput. From the the perspective of operator's: To increase the level of information transmission, applying sophisticated radio access technology (RAT) is the main approach for operators. Meanwhile, to improve the ability of the Wi-Fi offloading rate, it is necessary to develop advanced radio access techniques for operators, this is to maintain congestion and balance between one radio access with another. Cheung *et al*. [24] in his proposal to integrate cellular Wi-Fi systems with network selection games (NSG) for formulations to overcome the congestion-aware selection problem. NSG combines several practical considerations which include user mobility, Wi-Fi availability, switching time, and network switching costs based on usage. Based on simulation results in the 3G system shows significant results, but the system has not been tested on a 4G system. From the user's perspective, the study direction aims to be able to increase the average user rate. For this reason, [32] tries to find the optimal share of the traffic it gets. They developed a method that was used to collect data network and its analysis when used for offloading. The model used a heterogeneous network with the number of Radio Access Technology of M and the K number of access points. Galinina *et al*. [47] by adopting a new analytical model, by implementing a network architecture with dynamic data flow splitting at dual-RAT in a small dense cell.

3.5. Continuity

The Wi-Fi offloading scheme allows the EU to switch radio access. This can disrupt ongoing communication and significantly influence customer satisfaction. techniques according to the further incentive continuity is currently classified into four categories, namely real-time switches, relaying mechanisms, multipath mechanisms, and collaborative mechanisms. Table 3 provides this classification in more detail.

Table 3. The further incentive continuity

Further intensive continuity			
Real-time Switch	Relaying Mechanism	Multipath Mechanism	Collaborative Mechanism
Real-time Switch	D2D Communications	Multipath TCP	Opportunistic Offloading
Contact Aware Handoff	P2P offloading	IFOM (IP Flow Mobility)	MADNET

4. ADAPTIVE SELECTION SCHEMES

The expectation of users and operators to obtain low cost, low energy consumption, low latency, high bandwidth, and high data throughput services in radio access technology is very difficult today. Many researchers have proposed adaptive methods in Wi-Fi offloading. In this study a survey of the adaptive methods that had been previously proposed. In general, the most proposed adaptive schemes are based on computational modeling [3], [26], [48], [49].

4.1. Computational based adaptive scheme

Smartphones are owned by most people today with many application facilities and temperature sensors, accelerometer, GPS, and microphone [26]. Using existing sensors, user behavior can be analyzed. The eDOAS scheme is proposed based on energy-aware that works under the multimedia applications used by the user. This scheme adjusts the data transmission characteristics so that the battery life on the smartphone works longer by considering the quality of service provided [3]. The block of eDOAS is illustrated in Figure 5, which consists of two main blocks, first the Mobile Client or EU, and the second the eDOAS server.

The offloading computational method is to transfer the offloading method to the server, this is done to reduce resources, and leads to mobile cloud computing [26]. Within its framework, resource allocation and acceptance control mechanisms located on the edge servers offer mobile users the option to carry out their tasks. At a lower level, the edge server is tasked with ensuring service quality can be fulfilled for each network task that is formed by adjusting the behavior pattern and the edge server control mechanism is set linearly.

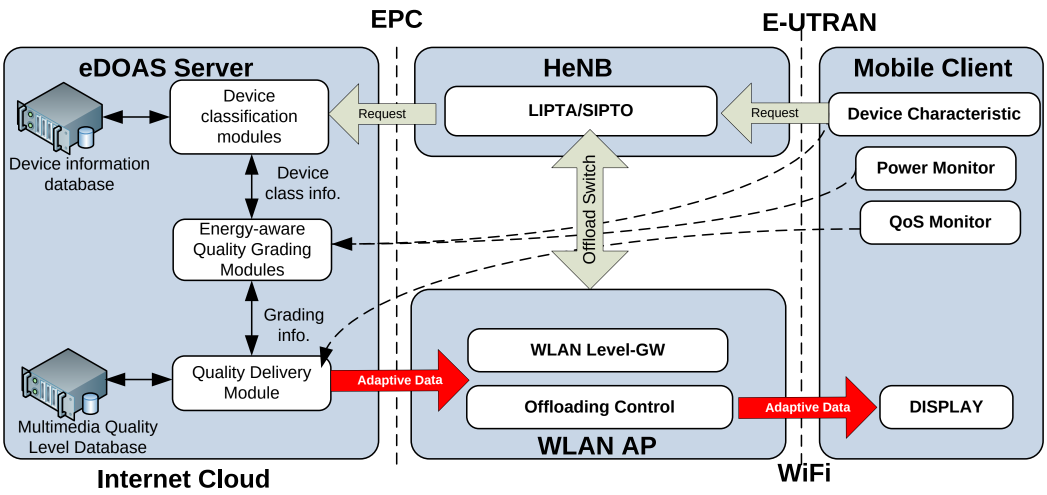

Figure 5. Energy-aware device-oriented adaptation scheme

For a higher level, the optimizer handles load balancing and application placement issues towards maximizing the number of offload requests. In contrast to traditional techniques that apply computational offload to a single server, the parallel offload method can improve system performance [30]. Static application component multi-partition algorithm is difficult to maintain optimality, this is due to the variability of the communication and computing environment according to the time-varying scenario. As a result of changing the environment too often, the algorithm execution becomes too frequent. The mobile cloud computing (MCC) computing offloading architecture is described in Figure 6.

Environmental variables have an impact on the cost requirements for the algorithm. The solution to solve the multi-partition problem of application components as a graphical mapping model. The mapping results will create a route discovery model problem. The adaptation method used uses a generic algorithm that is enhanced using the elite-base immigrant's mechanism. The result of this mechanism is dramatically able to provide more precise solution precision and increase transmission search speed and transmission process.

Another researcher proposed the stackelberg game (SaSG) model method assisted by software defined networking (SDN) for Wi-Fi offloading [50]. In his paper, MBS will use the received signal strength indicator (RSSI) to determine the Wi-Fi offloading process. Blockchain technology is proposed to provide Wi-Fi offloading on 5G systems that provide efficient data transfer [51]. By utilizing software-defined networking (SDN), operators can determine which users to offload to a Wi-Fi network regardless of the operator's network to which they subscribe. This proposal provides reliable services for sellers according to the transactions used. Its mechanism of action is described in Figure 7.

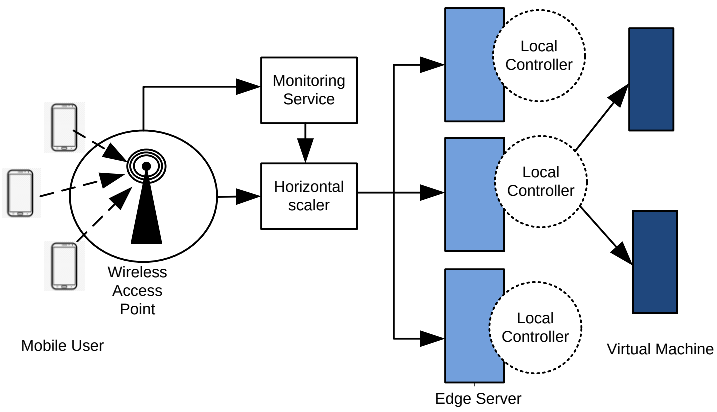

Figure 6. MCC computing demolition architecture, this system integrates the user with the end service

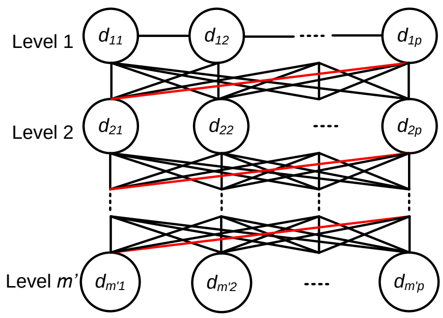

Figure 7. The search network and a solution path

4.2. Traffic based adaptive scheme

Other researchers tackled the problem of cellular network overload with a combination scheme of open wireless networks (OWN) and a biologically inspired attractor selection model [28]. This scheme is planned to be able to overcome balanced loads and reduce selfishness. In wireless local area networks (WLAN) and LTE networks, this method provides better performance.

This scheme implements the discrete Markov modulated poisson process (dMMPP), to make the queue get real-time network status. Furthermore, with the development of OWN architecture to select the right attractor model for the offloading process to overcome the problem of changing network signal density. With this method, the wireless network can be controlled automatically, and the load balance can be maintained. Also, system performance increases with lower delay and faster handover processing.

Figure 8 shows the machine to machine (M2M) communication architecture, where the system is divided into a control area containing an operating system (OS) that works based on a cloud-based controller, and various applications connected to the OS by the northbound protocol. This protocol controls situation-aware, attractor selection, and vertical handover. When the UE enters the overlay area, they can always access the appropriate network under OWN control. This is because the programmable data plane is embedded in the access point or base station. As M2M communication continues to develop, the need for data traffic will increase via cellular networks. To reduce data traffic, many efficient schemes were proposed, but failed because of poor adaption. Lei *et al.* focus on how to adaptively unload data traffic for mobile M2M networks [28], [47], [52]. Using the Continuous Time Markov chain, they propose a traffic offload rate scheme and a local resource consumption rate for the analysis results.

Ayub *et al*. [53] propose two methods at once, namely sequential cooperative rate enhancement (SCRE) and sequential offloading rate enhancement (SORE). Both methods are proposed to be applied to 5G systems. The SCRE method works through cooperative communication in which the user's data rate requirements are met through various associations of small cell base stations (SBS). However, SORE is based on Wi-Fi offloading, where users are relegated to the nearest Wi-Fi access point and use up their remaining capacity when they cannot meet the rates of a single SBS. To accommodate the two methods proposed switching between cooperation and offloading (SCO). From the results of his research, it is said that the SCRE method is more useful in networks that are not too dense. While the SORE method is more profitable on dense networks and available Wi-Fi networks.

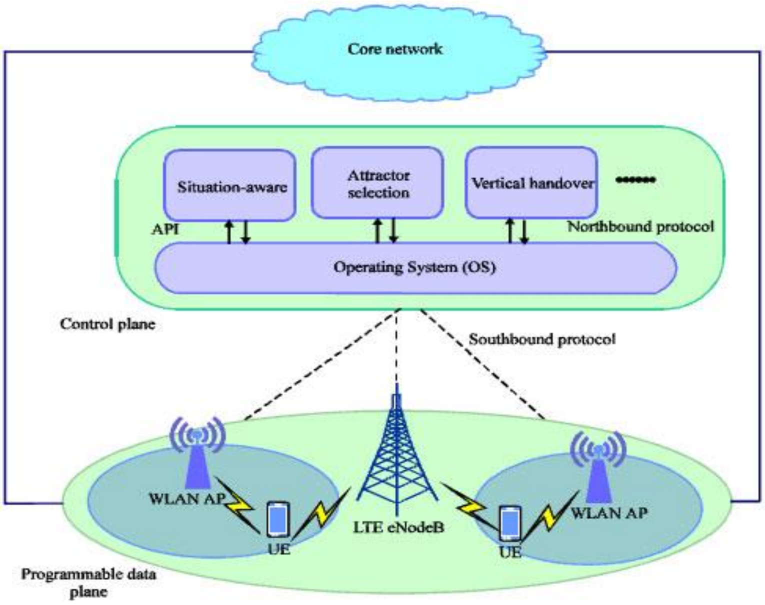

Figure 8. The 2M2 communication architecture

4.3. Energy based adaptive scheme

The eDOAS adapts to the underlying energy consumption to increase the battery lifetime of the mobile device [52]. However, the algorithm uses the computational based adaptive scheme. Local resource consumption rate is used to measure the resource of unsubscribed nodes, where at time t, the level of local resource consumption (v (t)) is the ratio of local resource consumption of unsubscribed nodes and the traffic unloading cellular data given by the equation:

$$\gamma(t) \triangleq f(\Omega(t), D(t)) \quad (2)$$

where $f(\Omega)$ is the function of resource consumption.

They introduced a new metric to measure the minimum time all subscription nodes receive mobile data known as minimum completion time. The equation is given in (3).

$$T_{min} \triangleq inf\, \{t : D(t) = N\} \quad (3)$$

where T_{min} is the minimum completion time.

4.4. Througput based adaptive scheme

Another adaptation is throughput based [10], they proposed the selection of attractors in heterogeneous wireless networks in designing adaptive algorithms for Wi-Fi offloading. This is shown in Figure 9. This mechanism uses computation to determine the offloading process. Many network access is available today to connect to the internet. Streaming video takes up the largest portion of bandwidth and represents a real challenge for service providers and the research community in general [54]. At the same time, the use of Wi-Fi is very massive in the indoor area. The layout that does not match the location has an impact on overlaying the coverage area and signal interference. While there are many empty holes without a signal which reduces user satisfaction. The alternative technology uses the white space TV (TVWS) network. This technology uses a sub-GHz frequency and matches its propagation characteristics. However, this technology provides lower performance than the 802.11 protocol standard. The study of this method is given in Figure 10.

Other researchers through connection aware balancing algorithm (CABA) brought to improve TVWS network end users [54]. According to the results of his research showing that the TVWS network can effectively increase the communication range, the drawback is that load balancing middleware is needed to achieve better performance.

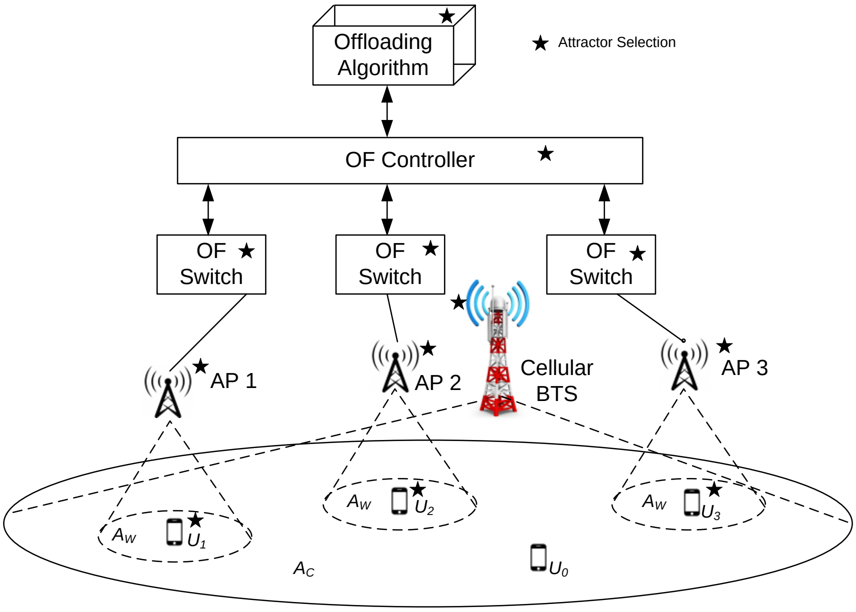

Figure 9. The network architecture

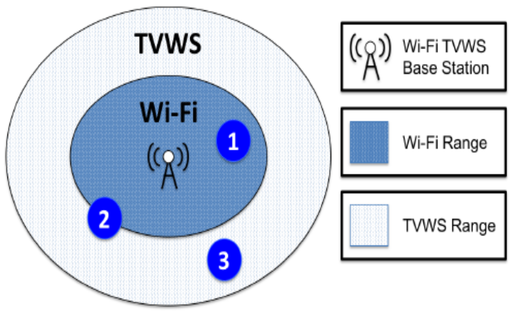

Figure 10. The studied scenario

Saliba *et al*. [55], to integrate the LTE-A network (5G) with the Wi-Fi network, before offloading it to the Wi-Fi network, a method is used to calculate the capacity of Wi-Fi access points (APs) that will be able to handle the transfer of advanced LTE capacity (LTE-A). This dimensional method is proposed by equalizing the throughput, between the two networks before Wi-Fi offloading is carried out. This method is proposed with the aim that the Wi-Fi offloading process does not reduce the level of service provided to the user.

4.5. The others adaptive scheme

In addition to the adaptive scheme above, there are still some researchers who use the adaptive scheme in Wi-Fi offloading as described below. The use of artificial intelligent and machine learning is proposed to deal with 5G systems that have heterogeneous networks[56].

4.5.1. Delay

High cellular data usage has implications for both users and providers [4]. The implication for providers with high use of mobile data is that it is expensive to provide infrastructure to upgrade existing systems. While the implications for users relying on cellular data connectivity result in high cellular data costs. The middle way is to divert some of the cellular data traffic via Wi-Fi where available. Other researchers propose a scheme to solve the problem of tolerant delay using dynamic and adaptive schemes. The scheme has four designs, namely adaptive, decision tree-based, hybrid, and lazy [4]. They were able to reduce cellular usage by 2 times or more compared to the non-delay tolerance approach. This adaptive method is also capable of performing up to a further 15% reduction in mobile data compared to fixed static delay tolerance values.

4.5.2. Cost

There has been an increase in the growth rate of cellular data traffic in the last 4-5 years. At the same time, the growth rate of Wi-Fi hot spots is also increasing. Subscribers tend to switch from cellular networks to Wi-Fi networks manually to reduce high mobile data costs. In this case, the operator loses the visibility of the customer and cannot control congestion in the network, and most importantly, cannot provide a guarantee of QoE to the customer [57]. To maintain QoE, a mobile network-centered near-real-time scheme is proposed to maintain this QoE.

4.5.3. Congestion control

Communication between M2M machines is progressing rapidly. The consequences is data congestion, and low quality of service issues in mobile networks where mobile networks were originally designed for voice-to-voice communication [58]. This system has not to support to work adaptively in more heterogeneous and complex conditions.

4.5.4. Mobility

Today's smartphone applications generally use MCC to provide convenience [59]. The main objective of MCC is to provide service availability, improved performance, and mobility features. This study proposes to improve the performance and availability of MCC services by using mobility-conscious adaptive offloading methods. A mobility-aware adaptive task offloading algorithm (MATOA), this algorithm was chosen to refer to dynamic changes in mobile content (for example, network status, bandwidth, latency, and location) used to make task offload decisions at runtime. In the radio access network selection in the RSS and optimal resources.

4.5.5. Multi-RAT

Other researchers highlight the different use of radio access technology [59]. They introduces the concept of cognitive cloud offloading in which a viable entire wireless interface of multiple radio access technology is used for offload computing. For offloading, computationally intensive applications are designed with the time and wireless adaptive heuristic method. This is to reduce energy consumption on mobile devices, reduce execution time, and efficient use of multiple RATs available on the device.

The proposed algorithm will simultaneously determine several parameters such as the place of execution, whether on a mobile system or in the cloud, the amount of data to be sent through each available interface of the multi-RAT device, and the order in which the application is scheduled.

4.5.6. Power

The availability of the ISM band for LTE-U provides an opportunity for research on this frequency. With the release of these bands, LTE provides flexibility to send data to its subscribers without a frequency permit. To use unlicensed bands, LTE-U must coexist with other wireless Wi-Fi technologies operating in unlicensed bands [60]. This could be possible because they both use different core networks, backhaul, and deployment plans, but with the same frequency, there will be interference.

Duet, provides a solution at the medium access control (MAC) layer that allows LTE-U and Wi-Fi nodes to operate simultaneously, with predetermined property scenarios, namely there is no change in the Wi-Fi framework, second, high-performance LTE-U networks, and Wi-Fi in static and dynamic load scenarios, and the third is the resistance to fully and partially connected networks. The duet algorithm works with an ON/OFF duty cycle mechanism.

In general, adaptive schemes have been widely used, however, the adaptive schemes have different implementations. Table 4 provides an overview of the adaptive schemes used by some previous researchers. Meanwhile, [61] proposed an adaptive rate method for the Hybrid-CDMA system. In their proposal, they combine direct sequence and fast frequency hopping into a code-division multiple-access cellular system. The system discussed is purely data speed on the cellular system and not Wi-Fi offloading.

Table 4. Adaptive selection schemes

Performance Evaluation	Year	Adaptive Offloading Schemes												Network
		Throughput	Power	Cost	Energy	Mobility	Traffic	Computation	Sampling	Sensing	Delay	Congestion	Multi-RAT	
Sensor Sampling [26]	2012							√	√	√				3G
eDOAS [3]	2014				√			√						IEEE 802.11g
OWN [10]	2014						√							LTE
Dynamic delay tolerance [60]	2015										√			Wi-Fi
Wi-Fioffloading ratio[10]	2015	√												Heterogeneous
SaSG[50]	2019		√					√						5G
Blockchain[51]	2020			√				√						5G
AOM[52]	2016				√		√							Cellular M2M
SCRE, SORE, SCO[53]	2021	√		√			√							5G, Beyond 5G
Artificial Inteligent, Machine Learning[56]								√						5G, 6G
Dichotomic classification of subscribers [57]	2017			√										LTE-Wi-Fi and femtocell-Wi-Fi
Attractor-selection-based congestion control [58]	2019											√		3GPP LTE
MATOA [59]	2019					√								Cellular, Wi-Fi, Bluetooth
Resource allocation [59]	2019							√						3G/4G or LTE
CABA[54]	2017	√												TVWS and Wi-Fi
Elite-based immigrants mechanism [49]	2015							√						Wi-Fi, Bluetooth, Zigbee, 3G/LTE
DOA [28]	2016												√	LTE, Wi-Fi
Duet [60]	2017		√											LTE-U, Wi-Fi
Wi-Fi Dimensioning [55]	2019	√												LTE (A) 5G, Wi-Fi

5. CONCLUSION

Wi-Fi offloading is the most suitable solution to address the data traffic needs experienced by cellular telephone subscribers today by switching their radio access to a Wi-Fi network. There have been many adaptive schemes proposed by previous researchers, the schemes are different, but computational becomes many choices in adaptive schemes. With a computational scheme, various parameters are involved in the calculation. These parameters are radio signal strength, radio access technology, cost, mobility, power consumption, continuity, and traffic data. From the survey results shown in Table 4, there is no proposed adaptive algorithm based on the QoE. This provides an opportunity for further research where the Wi-Fi offloading scheme uses the perspective user or user experient options. In addition, open research uses artificial intelligence and machine learning methods as adaptive methods.

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BIOGRAPHIES OF AUTHORS

Ruliyanta received the B.Sc. degree in Telecommunication Engineering National University, Indonesia, the M.Sc. degree in Telecommunication Enginering Indonesia University, Indonesia. Currently working as a lecturer at the Faculty of Engineering and Science, National University, Indonesia. In his work, he served as Vice Dean for Student Affairs. Research is being conducted in the field of telecommunications, heterogeneous network, and wireless communication. He can be contacted at email: ruliyanto@civitas.unas.ac.id.

Associate Prof. Dr. Mohd Riduan Ahmad received the degree (Hons.) in computer system and communication engineering from Universiti Putra Malaysia, in 2003, the M.Eng. degree with a specialization in cross layer design of MAC protocols for multi-in multi-out-based wireless sensor network from the University of Wollongong, Australia, in 2008, and the Ph.D. degree with a specialization in atmospheric discharges from Uppsala University, Sweden, in 2014. Between 2015 and 2016, he was with MIT, USA, where he investigated characterization of microwave radiation emitted by lightning flashes. He is currently an Associate Professor and Deputy Dean (Research and Postgraduate Studies) with the Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka. He can be contacted at email: riduan@utem.edu.my.

Associate Prof. Dr. Azmi Awang Md Isa has received the B.S degree from Universiti Teknologi Malaysia (UTM) in 1998, received the M.S degree from Universiti Kebangsaan Malaysia (UKM) in 2004, and obtained his PhD degree in communications systems from Lancaster University, UK in 2011. He is a Professor at University Teknikal Malaysia Malaka, and Senior Lecturer and Deputy Dean of the Center for Graduate Studies, Faculty of Electronic and Computer Engineering (FKEKK) Universiti Teknikal Malaysia Melaka (UTeM). His research interests include wireless location technologies, Mobile Radio & Satellite Communications Navigation Systems. He can be contacted at email: azmiawang@utem.edu.my.