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SDN-Based Data Offloading for 5G Mobile Networks

Mojdeh Amani[1], **Toktam Mahmoodi**[1], **Mallikarjun Tatipamula**[2], **and Hamid Aghvami**[1]
(1. King's College London, The Strand, London, WC2R 2LS, UK;
2. F5 Networks, San Jose, CA 95134, USA)

Abstract

The rapid growth of 3G/4G enabled devices such as smartphones and tablets in large numbers has created increased demand for mobile data services. Wi-Fi offloading helps satisfy the requirements of data-rich applications and terminals with improved multimedia. Wi-Fi is an essential approach to alleviating mobile data traffic load on a cellular network because it provides extra capacity and improves overall performance. In this paper, we propose an integrated LTE/Wi-Fi architecture with software-defined networking (SDN) abstraction in mobile backhaul and enhanced components that facilitate the move towards next-generation 5G mobile networks. Our proposed architecture enables programmable offloading policies that take into account real-time network conditions as well as the status of devices and applications. This mechanism improves overall network performance by deriving real-time policies and steering traffic between cellular and Wi-Fi networks more efficiently.

Keywords

mobile data offloading; LTE/Wi-Fi interworking; policy derivation; network selection; software-defined networking; dynamic policies; 5G mobile networks

1 Introduction

In 2013, mobile phones overtook PCs as the most common Internet access device worldwide, and by 2015, more than 80% of handsets sold in mature markets will be smartphones [1]. According to forecasts, global mobile data traffic will grow 13-fold between 2012 and 2017, which is three times faster than fixed IP traffic [2]. Mobile network operators will carry the bulk of Internet traffic in the future, but they face significant challenges in addressing needs associated with increased traffic demand. To meet this demand, mobile operators are investing in more network capacity. Scarcity of spectrum is forcing such operators to deploy smaller cells and utilize unlicensed spectrum, such as Wi-Fi. Availability of built-in Wi-Fi on smartphones and unlicensed spectrum makes Wi-Fi a natural solution for accommodating increased traffic and maintaining the quality of users' connections.

To this end, mobile data offloading, which refers to the use of complementary network technologies to deliver data originally targeted at mobile/cellular networks, has already become a key solution for meeting traffic demands [3]-[5]. Various platforms, including opportunistic communications, have been considered for mobile data offloading [6]. Furthermore, mobile networks must support various applications, such as voice and streaming, as well as best-effort services on a single IP-based infrastructure. Each of these converged services has quality of service (QoS) requirements, in terms of latency, packet loss and data rates, that must be met through efficient allocation of wireless network resources and cannot that be met only by provisioning the network. One of the main challenges in data offloading is making real-time decisions on offloading the flows and services/applications of different users while taking the condition of available networks and QoS needs of flows into account. In this regard, previous research has focused on providing seamless movement between different access networks during data offloading [7]. Dual stack mobile IP has also been considered to enable simultaneous use of two interfaces [8]. All the technologies involved in mobile data offloading from the LTE network are ready for deployment and, in fact, can be deployed by operators. However, we lack efficient offloading techniques and decision-making criteria.

The mobile networks architecture proposed for 4G/LTE provides easier management compared with earlier architectures because it separates signalling plane functions, such as mobility management, policy-making, and charging. Despite this, today's 4G/LTE architecture is not yet as flexible or programmable as it could be. For example, the 4G/LTE network can provide QoS guarantees and differentiated services to the user through policy-charging and rules function (PCRF) nodes. Policy and charging control (PCC) ensures that the user has guaranteed QoS for a particular subscription and service type. Today's PCCs are user-aware and application-aware but do not have awareness of network congestion.

We propose placing the policy control closer to the wireless access and deriving policies according to radio network information as well as previously used user and application information. This can significantly improve mobile data offloading. We propose an abstraction layer based on software-defined networking (SDN) [10] that integrates network resource management (NRM) with radio resource management (RRM) and enables programmable, dynamic policy functions.

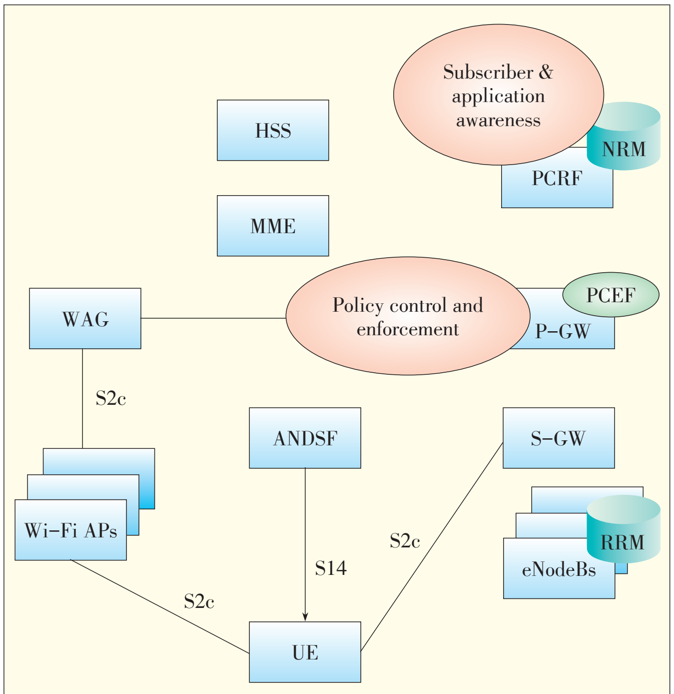
The remainder of this paper is organized as follows. In section 2, we give an overview of current LTE/Wi-Fi interworking architecture. In section 3, we discuss network selection and related challenges. In section 4, we give details of the proposed interworking modification for better QoS. In section 5, we present the policy derivation and offloading mechanism. In section 6, we conclude with a summary of programmable data offloading policies.

2 Cellular and Wi-Fi Interworking Architecture

The goal of mobile data offloading is to dynamically redirect selected traffic towards the lower-cost RAN. 3GPP has been developing new standards and architectures to support the simultaneous use of different cellular access networks, such as LTE and femtocells, as well as non-3GPP access networks, such as Wi-Fi. 3GPP standardization covers the native integration of trusted and untrusted non-3GPP IP access network into the EPC [6]. This standard treats Wi-Fi RAN as valid an access network as any other 3GPP RAN and enables operators to use standard-based EPC components to integrate different types of access networks. It also facilitates interoperability between these networks. Such integration ensures a good level of inter-operability between different access types.

In this paper, we focus on trusted non-3GPP access network architecture, i.e., Wi-Fi access network architecture, which is owned by the cellular operator. S2c and S2a are the two interfaces that provide control and mobility support between non-3GPP access network and packet gateway (P-GW). They also forward Wi-Fi traffic to the EPC (**Fig. 1**). S2c provides mobility and control support between user equipment (UE) and P-GW over the non-3GPP access network. S2a provides control and mobility support between the trusted non-3GPP access network and P-GW. The serving gateway (S-GW) serves between the LTE and mobile access gateway (MAG) of Wi-Fi and reports to the PCRF. The S-GW also sets bearer QoS parameters. Moreover, eNodeB, S-GW and P-GW are involved in other control plane functions, such as location update and mobility, in coordination with the mobility management entity (MME).

Access network discovery and selection function (ANDSF) is an entity within an evolved packet core (EPC) of the system architecture evolution for 3GPP mobile networks. ANDSF helps UE to discover non-3GPP access networks, such as Wi-Fi for data communication, in addition to 3GPP access networks and provides the policies used to access these networks. When combined with ANDSF, the Mobility over GPRS Tunneling Protocol based on S2a enables an operator to benefit from controlled automatic network discovery and selection for the user. This results in a seamless user experience. ANDSF uses a standard S14 interface to communicate information and policies to the UE. This information is organized within nodes of a managed object that contains several nodes, including nodes for discovery information, intersystem mobility policies, and intersystem routing policies. S14 is the only standard interface for ANDSF, and any interaction between the ANDSF server and other network elements is outside the scope of current 3GPP standards.



ANDSF: access network discovery and selection function
HSS: home subscriber server
MME: mobility management entity
NRM: network resource management
PCEF: charging enforcement function
PCRF: policy charging and rules function
P-GW: packet gateway
RRM: radio resource management
S-GW: serving gateway
UE: user equipment
WAG: wireless application gateway

▲Figure 1. 3GPP architecture for the non-3GPP IP access integration into the EPC.

These new measures in the standard enable seamless handover and traffic steering so that users have continuous data service as they roam between cellular, small cell, and Wi-Fi networks. Hence, users can benefit from secure, transparent services regardless of the types of access technology.

3 Network Discovery and Selection

Wireless networks are becoming increasingly heterogeneous. In addition, more mobile devices are capable of simultaneously operating on multiple technologies, i.e., 3G, 4G and Wi-Fi radio. Given this, selecting the best network for a user at any given time and location is crucial for optimizing the access of that user. The main consideration in any network-selection strategy is network-based information, which informs decisions on network selection and traffic steering, as well as the different ways of distributing this information to devices. Information from traffic-steering policies, the real-time network condition of both cellular and Wi-Fi networks, and subscriber profiles are all necessary for optimal network selection. In addition, the device itself contains important information, such as battery usage, radio conditions and relative motion, which should be considered when making a decision. Thorough consideration of all these parameters makes network selection a very complex problem. In this section, we discuss the possibility of including various decision criteria.

3.1 ANDSF

ANDSF was defined in the recent 3GPP standards as a framework for issuing policies to a device where traffic routing decisions between a cellular and Wi-Fi access network are being made. The device periodically determines the validity of policies in terms of location and time of the day. Many operators are interested in using ANDSF for policy-based network selection and traffic steering. A few of these operators, such as Telefonica, are already trialing the ANDSF server solution. Although ANDSF provides a standard framework for distributing flexible, operator-defined network-selection information and policies, it does not capture additional information in an operator's network, e.g., network condition, which could be useful to derive dynamic policies and communicate them with the device. The key issue in this framework can be addressed by implementing an ANDSF client in devices [11]. This client communicates with an ANDSF server in the network and distributes ANDSF policies to the device so that networks can be dynamically selected and traffic steering decisions can be made [9]. Deriving appropriately dynamic policies and distributing them to the ANDSF client enables an operator to steer traffic between Wi-Fi and cellular networks, create better user experience, and better utilize radio resources.

3.2 Challenges

One of the most important aspects of efficient network selection is the current network condition of all available access networks. For example, the real-time load on the radio link of a cell site significantly impacts the QoS of a given user and can influence the selection of that access network. The 3GPP standard allows user-subscription-dependent policies for ANDSF; however, there is no standardized interface between ANDSF and the user's subscription/profile information, i.e., between ANDSF and the home subscriber server (HSS). In fact, 3GPP enables ANDSF to communicate with the UE via S14 interface. The data obtained from the UE is mainly the UE's location and device type [10]. This information is rather static, but various other dynamic data can significantly affect efficient network selection.

Operators are pursuing solutions in which more dynamic criteria are used in the selective offloading of traffic between all available RANs. On the user side, network-selection criteria that are of interest to the operator include user subscription level and user profile, which includes usage history or caps. Network-driven criteria include different types of Wi-Fi access network, e.g., trusted, public or private, and venue information. Despite this, ANDSF policies are static because ANDSF does not receive any input except that from the UE via the S14 interface. In other words, existing ANDSF policies do not take into account either network condition, such as load and congestion, or UE conditions.

We argue that policies based on an awareness of network, application, and user-profile at the ANDSF can significantly improve both network utilization and user experience. To derive dynamic policies, first we need to determine what type of information must be considered, how to collect and capture this information, and how to derive policies and communicate them to UE for efficient network selection. In the next section, we discuss the challenges related to designing a policy entity that has an awareness of network, application, and user profile, and we present one solution based on it. Our solution is a centralized solution that is, in fact, one way of realizing SDN. An alternative way could be a fully distributed user-centric approach, where the UE collects data and selects a network. We will exploit this family of solutions in our future work.

4 Programmable Data Offloading

We envisage a policy entity that can receive the network, application, and user-profile information; derive the policy, and distribute it to the ANDSF server in the network. Complexity arises from the fact that the network, application, and user-profile data are available at different parts of the end-to-end communication path. For example, the UE is the only entity aware of effective radio condition, throughput over existing connection, active applications, pending traffic, and battery levels. We design a centralized architecture, where policies are driven at a central controller within the network architecture. Here we describe how data is collected and policies derived.

4.1 Decision Criteria and Policy Control

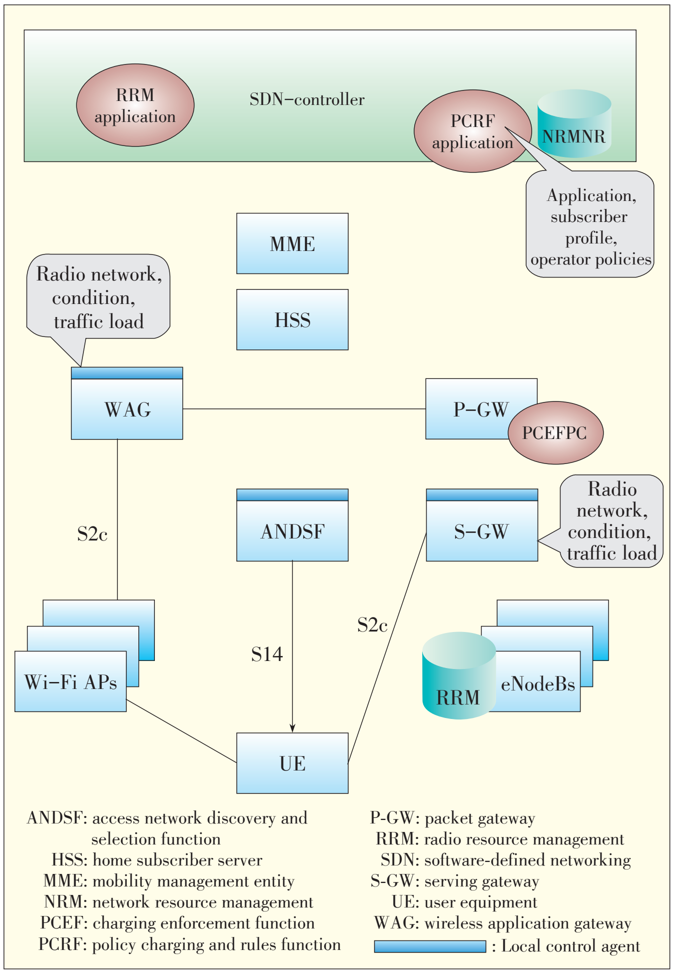
In the architecture in Fig. 1, the policy and charging enforcement function (PCEF) in the P-GW enforces policies and maps service data flows to the bearer that is to be mapped to the underlying transport network. The PCRF is an LTE policy manager that uses operator policies, network information, and user profile stored in the HSS to make decisions according to a set of pre-defined rules and functions. The PCRF is also responsible for QoS authorization, i.e., authorizing the treatment of each traffic flow. Today's policy controls have awareness of users and applications but not congestion within the network [12]. Fine-grain control on various entities in the mobile network is crucial so that operators can allocate resources and cheaply maintain and expand the network. It is also important for employing dynamic policies, i.e., for managing the traffic and selectively offload the traffic between different access networks according to the current network condition.

When managing traffic, the policy enforcement point can either be the core network or access network. At the core, policies are enforced in the P-GW, which has deep packet inspection (DPI) functions. This is similar to today's architecture (Fig. 1). Service information does not have to travel at all, and the DPI engine can store subscriber information from the policy controller. This enables congestion and location to be estimated. The central solution described here requires simple integration of the DPI engine into the policy controller. On the other hand, congestion information is extremely dynamic, i.e., it changes rapidly and by the time values sent from RAN are received by the P-GW, the information is no longer valid. Various studies show that bad decisions were made 40% of the time when outdated congestion information was used.

Moreover, estimation based on current traffic is not possible for the DPI engine because:

- The policy controller lacks a feedback mechanism. Simple questions such as "Is 1 Mbps for P2P is enough or are we over penalizing?" cannot be answered.
- The policy controller only has a general indication of reduced throughput, which may occur as the result of poor coverage or congestion. Only the RAN can differentiate between these two causes.
- Quite often, a RAN is shared between different operators, or perhaps the operator is using multiple access points. In these cases, the policy controller cannot see all traffic passing through congested cells.
- Cell capacity depends on the coverage of individual subscribers and varies, even with weather conditions. There may be additional reserved bandwidth for future bearers with guaranteed data rate or other similar cases that affect total cell capacity. In other words, cell capacity varies over time, and the policy controller receives no information about the variations in capacity of the congested cells.

One alternative for addressing these challenges is to move the policy enforcement point to where congestion occurs so that we do not need to transfer dynamic information anywhere. In this way, the scheduler continuously prioritizes data packets and subscriber sessions. The scheduler has perfect knowledge about the location of the user, traffic, and real congestion conditions at the location. Then, the policy controller takes service information from the DPI function and changes QoS parameters such as traffic handling priority, maximum bit rate, guaranteed bit rate, or QoS Class Identifier (QCI). In LTE, there it is also possible to create a dedicated bearer for a specific traffic flow requiring differentiated QoS treatment at the policy-enforcement point. This architecture (**Fig. 2**) makes network management more complex. It is still not clear where the policy control should be located in order to increase efficiency but not significantly increase complexity.



▲**Figure 2. SDN-controlled network selection.**

4.2 SDN Controller and Mobile Data Offloading

As discussed earlier, deriving real-time policies for selective offloading of different services/applications according to the dynamics of network is potentially complex. A programmable interface similar to that in SDN facilitates offloading by providing end-to-end communication between network elements and by pushing corresponding forwarding rules to local elements, i.e., eNodeB and P-GW. In our proposed architecture, the control-plane functionality of the gateways is decoupled and located at the SDN controller as applications. The gateways run local control agents. The SDN-controller derives offloading policy functions and rules by combining information from the RRM and PCRF applications. The radio network condition, defined by wireless condition and traffic load, is measured frequently by the local control agents. This enables an operator to monitor traffic in real time, provide per-subscriber QoS through programmable application modules in the SDN controller, and derive forwarding rules accordingly. These policies and forwarding rules are periodically sent to the local control agents in the access network and are forwarded to the UE. The LTE and Wi-Fi interworking architecture, including SDN controller and interactions with local control agents are shown in Fig. 2. The two main parts of this architecture are the SDN controller and logical control agents.

The SDN controller in this architecture is an abstraction model that runs programmable applications modules, such as RRM and PCRF. The PCRF application module has subscriber and application information, and the RRM application module collects radio access network conditions, such as traffic load and cell capacity. The SDN controller combines the information from these application modules in order to derive a single set of policies and rules that are sent periodically to the local control agents.

To address the scalability issue and challenges raised in section 3.2, we propose local control agents in the network gateways, i.e., P-GW, S-GW and WAG as well as in the RAN. These local control agents should have some measurement and control capabilities that are authorized by the SDN controller. For example, the agents that run on the gateways can measure QoS parameters, such as delay and resource utilization, and compare the traffic counters with the threshold. These agents can then notify the SDN controller when the threshold has been exceeded. To communicate back with the controller, an interface similar to OpenFlow [14] is required at the local agents. This also enables the agents to exercise simple control, such as changing the weight or priority of a queue, when the traffic counter exceeds the threshold.

5 Policy Derivation and Offloading Mechanism

5.1 Policy Derivation

In order to derive policies, network load information, signal threshold, and operator policy are combined in the SDN controller. This section explains the parameters that are considered when deriving policies in a few different scenarios.

5.1.1 Network Load

In a scenario where the operator controls both a cellular and Wi-Fi networks in a given area and the cellular network is not congested, the operator may prefer to serve customers via the cellular network. As the load on the cellular network increases, potentially impacting user experience, the operator may want to start steering some of the traffic towards the Wi-Fi network. As the cellular network becomes even more congested, the operator may want to steer even more traffic towards the Wi-Fi network. This policy can be made even more effective if the condition of the radio on the cellular network is taken into account. For example, cell-edge users experiencing the worst radio conditions on the network can be steered towards the Wi-Fi network first. Also, when the cellular network is congested, the operator who controls both the cellular and Wi-Fi networks may want to steer users experiencing poor cellular radio from the cellular network to Wi-Fi. As the cellular network becomes more congested, the operator may want to steer more users towards Wi-Fi. Even when the cellular network is not congested, some users may experience poor radio on the cellular network but have access to a Wi-Fi network with acceptable quality and load. In this case, the operator may want to serve that user's traffic via Wi-Fi instead of the cellular network. Additionally, the exact thresholds at which certain users are steered to Wi-Fi depend on the distribution of eNBs and Wi-Fi access points (APs) in the network as well as the instantaneous distribution of UEs in the vicinity. Thus, the mapping between load level and the signal strength at which a user is steered to Wi-Fi is not static.

5.1.2 Signal Strength

A signal strength threshold can also be included in the policy to ensure the correct users are steered towards Wi-Fi while others are kept on the cellular network. For example, when the cellular load is 70%, the signal strength threshold may be −108 dBm, but when cellular load is 88%, the signal strength threshold may be −105 dBm [15]. This signal strength threshold

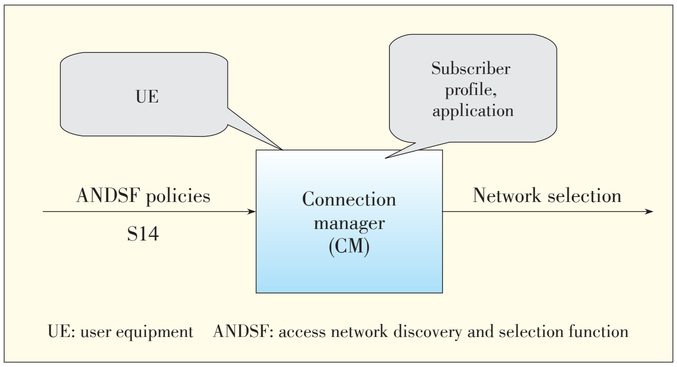
indicates a minimum received signal strength below which UEs should attach to available and acceptable Wi-Fi APs. Specifically, the UE compares experienced signal strength with the signal strength threshold of the received policies via ANDSF and then selects a network. An operator can first move UEs with poor cellular radio to Wi-Fi APs in a smart way that takes into account the cellular network load as well. Furthermore, the signal strength threshold may be combined with thresholds provided by operator policies, e.g., in a case where different policies are defined for different types of users. Alternatively, the operator might simply want to introduce different tiers of service. For example, the operator policy might seek to steer heavy video users to Wi-Fi while keeping subscribers who complain about Wi-Fi service on the cellular network.

5.1.3 Random Generated Value

Steering large numbers of UEs between cellular and Wi-Fi APs may dramatically affect instantaneous network conditions. For example, if a large number of users were steered towards Wi-Fi, the load on the cellular network would be reduced. This reduction could cause those same UEs to try and reselect the cellular network because it is now a much more desirable access network than before. Because all the users move back to the cellular network, the load increases and causes users to be steered back towards Wi-Fi. Thus, UEs ping-pong between the cellular and Wi-Fi networks as long as this process continues [15]. To avoid the ping-pong effect, a calculated integer can be included in the policy along with load level and signal strength threshold. This calculated integer is used to steer a subset of targeted UEs together rather than all targeted UEs at once. Therefore, a random integer a is generated in the range of 0-10 and is distributed in the policy. Furthermore, each UE generates a random value b in the same range. If $b < a$ and other conditions are satisfied, then a given UE is steered towards the Wi-Fi AP; otherwise, the UE stays on the cellular network. In this way, a given fraction of the targeted population is steered towards Wi-Fi at any given time. The operator can control this fraction by random distributed values. In the case of different service tiers for different user types, more than one calculated value can be distributed, and each value is targeted at a specific class of user with similar service needs.

5.2 Offloading Mechanism

The local control agents in the RAN and access gateways collect information, such as drop rate, utilization and traffic load, periodically and report it back to the SDN controller. The SDN controller combines this information with the operator's policies and subscriber's profile in the PCRF, derives the policies and forwarding rules, and communicates these policies and rules to the local control agent in ANDSF via an interface similar to OpenFlow [13]. Each mobile device is expected to have a connection manager (CM) [14], which is a functional component that takes ANDSF policies and user preference as input and combines them with the local conditions of UEs in order to offload and steering traffic (**Fig. 3**). The ANDSF dynamic policies include but are not restricted to a variety of parameters, such as operator policies, cellular and Wi-Fi conditions (e.g., traffic load), Wi-Fi quality (including packet loss, RTT and throughput), user subscription profile, time of the day, and location. The local condition of a UE includes movement of the mobile device relative to one or more APs, mobile battery usage, and application requirements (e.g., service continuity and throughput). The relative movement of a device towards an AP can be calculated within the device. There are a number of ways of performing this calculation, such as extrapolation via the rate of change in AP signal strength measured by the UE or estimation by the device according to implementation-dependent mechanisms. The policies are prioritized, and each is validated according to the local condition of the UE. The CM selects the network and steers traffic according to a valid policy. The simplest mechanism may include only two policies, one for when cells are congested and another for when cells are not congested. Both policies would be sent to the UE for use when in a valid area at a designated time of the day and would be updated by the ANDSF only when there is a change in conditions, such as long-term busy hour. Another example could be providing different cellular network traffic load thresholds to the UE according to the type of subscriber. One such threshold, *Cellular_Load_Max*, is for heavy-streaming users, and another threshold can be specified for high-priority users. Therefore, operators can obtain a desirable outcome by defining a policy upon triggering of congestion in a cellular network so that heavy-streaming users are moved to Wi-Fi before high-priority users.



▲Figure 3. UE architecture.

Supporting per-UE or per-cell policies does not mean that the new ANDSF policies should be pushed to UE whenever it changes location or that unique policies need to be maintained for a large number of cells. The frequency with which these policies are updated can be adjusted according to significant changes in network condition and availability of communication resources between the controller and access networks. Hence, during busy hours, a new policy derivation is triggered when a cell is congested. This derivation is based on the received data. The offloading mechanism here offers 1) dynamic policies because NRM and RRM are converted to software applications, 2) robust network-selection mechanism because a precise network condition, such as congestion in the backhaul, is captured, 3) efficient network selection because user preference and application requirements are taken into account, and 4) simplicity because the control plane functions are abstracted and communication between them is simplified.

6 Conclusion

Wi-Fi has become an increasingly popular access mode enabling wireless carriers to meet the capacity demands of mobile data users. The amount of traffic carried over Wi-Fi networks has grown dramatically in recent years and is projected to continue to grow in the years to come. To address the issues related to growing demand, we explore state-of-the-art Wi-Fi/cellular integration and propose a modified architecture that enhances key aspects of this integration and facilitates evolution towards 5G mobile. Such aspects include network discovery and selection, traffic steering, and the effect of policies and rules on traffic steering. In this paper, a programmable policy function derivation mechanism is proposed and enabled through the use of an SDN controller in the mobile backhaul. Our proposed mechanism takes into account real-time network condition as well as existing user and application information in order to control offloading policies and efficiently accommodate traffic on cellular or Wi-Fi access networks. We couple network resource management with radio resource management in the form of application modules at the SDN controller. This enables us to derive offloading policies that optimize both cellular and wireless resources.

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Biographies

Mojdeh Amani (mojdeh.amani@kcl.ac.uk) worked in cellular industry after graduating with a BSc degree in telecommunications. She received her MSc in digital signal processing and PhD in telecommunications from King's College London. Her research interests include QoS provisioning, resource management, data offloading in next-generation heterogeneous wireless networks, cloud computing, and software-defined networking. She has an ongoing interest in advances in science and their applications beyond research. She has publications on different aspects of next-generation mobile networks.

Toktam Mahmoodi (toktam.mahmoodi@kcl.ac.uk) works in the Department of Informatics, King's College London. She received her BSc degree in electrical engineering from Sharif University of Technology, Iran, in 2002. She received her PhD degree in telecommunications engineering from Kings College London in 2009. From 2010 to 2011, she was previously a postdoctoral research assistant in the Intelligent Systems and Networks Group, Department of Electrical and Electronic Engineering, Imperial College London. From 2006 to 2009, she was a PhD research assistant in the Core-4 Efficiency Program, Virtual Centre of Excellence in Mobile and Personal Communications (Mobile VCE). She has previously received the IEEE Best Paper Award from IEEE ICC and IARIA E-Energy. She is a member of IEEE and the ACM and has been on the Program Committee of number of IEEE flagship conferences.

Mallikarjun Tatipamula (m.tatipamula@f5.com) is vice president and CTO of service provider and cloud solutions at F5 Networks. He is responsible for innovation and implementation of new and disruptive technologies across the company. Mallik Tatipamula has more than 23 years' experience with telecommunication and networking technologies and has held leadership roles at Ericsson, Juniper, Cisco, and Motorola. He is a fellow of IET and has co-authored more than 100 patents and publications and two books on networking. He has a PhD in information and communication engineering from the University of Tokyo. He received BS degree from the Indian Institute of Technology, Madras, India. He has delivered lectures on networking at Stanford University, Tsinghua University China, and Beijing University of Posts and Telecommunications. He is currently a visiting professor at King's College London.

Hamid Aghvami (hamid.aghvami@kcl.ac.uk) is director of the Centre for Telecommunications Research, King's College London. He leads a team that is working on numerous mobile and personal communications projects supported by government and industry. From 2001 to 2003, he was a member of the Board of Governors of the IEEE Communications Society. From 2004 to 2007, he was a distinguished lecturer of the IEEE Communications Society. He has also been a member, chairman, and vice-chairman of the Technical Program and Organizing Committees of many international conferences. He is the founder of the International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), a major yearly conference attracting around 1000 attendees. He has published more than 700 technical papers and given invited talks and courses worldwide on various aspects of personal and mobile radio communications. He has received numerous awards for his technical contributions to the communications field and for his services to scientific and engineering communities. He is a fellow of the Royal Academy of Engineering and the IET.