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Carrier Wi-Fi: the next generation

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Carrier Wi-Fi: the next generation

By controlling whether or not a device should switch to and from Wi-Fi, and when it should switch, cellular operator networks will be able to provide a harmonized mobile broadband experience and optimize resource utilization in heterogeneous networks.

RUTH GUERRA

Next generation carrier Wi-Fi will overcome existing coordination issues in multi-RAT environments to become an integrated component of mobile broadband offerings. Guaranteeing the best mobile broadband experience and ensuring that resources in a heterogeneous network that includes Wi-Fi are utilized in an optimal way, is only possible if subscribers are connected to Wi-Fi when this is the best option for them and for the entire network. While this may sound obvious, the way subscribers currently switch to and from Wi-Fi is not optimal. Today, the decision to connect to Wi-Fi is taken by the device according to one basic principle: if Wi-Fi is available, then use it for data traffic.

However, this approach is shortsighted because it does not take into consideration real-time information about all the available resources. In a heterogeneous network, resources can include 2G, 3G, LTE, macro, small cells, different carriers, different protocols (802.11g, 802.11c) as well as different channels. In addition, devices do not take into account the activity of other UEs, and so each decision to switch to or from a Wi-Fi network is made independently, and without any consideration for load balancing. In short, current practice is inherently inefficient.

Background

The smartphone revolution and the near-ubiquitous support for Wi-Fi of modern devices have created new business opportunities and new challenges for telcos. Operators have so far deployed over 2 million Access Points (APs) in public spaces, and there are currently about 8 million hotspots worldwide. But why is there a need to integrate Wi-Fi into operator networks? The simple answer is that this technology is a good complement to existing solutions, and in certain conditions, it is particularly appropriate for handling spikes in data traffic. But to work well, it needs to be integrated.

So, the main factors that next generation Wi-Fi will capitalize on are:

- the vast amount of unlicensed spectrum that can be used by this technology without the need for any regulatory approval;
- its ability to offload data traffic, complementing existing indoor solutions, such as small cell and DAS;
- the near-ubiquitous device support for this technology – including UEs that are non-cellular;
- the evolution of small cells to support both cellular and Wi-Fi technology; and
- a new level of maturity – exemplified by the development of, and device support for, new standards and products, such as Hotspot 2.0, 802.11ac, EAP authentication and additional solutions currently being defined, such as S2a mobility, and 3GPP/Wi-Fi integration.

BOX A Terms and abbreviations

AES	Advanced Encryption Standard
AKA	Authentication and Key Agreement
ANDSF	Access Network Discovery and Selection Function
AP	Access Point
BSC	base station controller
BSS	basic service set
CSMA	carrier sense multiple access
DAS	Distributed Antenna System
DPI	deep packet inspection
EAP	Extensible Authentication Protocol
GTP	GPRS Tunneling Protocol
HLR	home location register
HSS	Home Subscriber Server
LI	Lawful Interception
MME	Mobility Management Entity
MS-CHAP	Microsoft's Challenge-Handshake Authentication Protocol
MWC	Mobile World Congress
NAS	non-access stratum
PLMN	Public Land Mobile Network
RAT	radio-access technology
RF	radio frequency
RNC	radio network controller
RRM	Radio Resource Management
RSRP	reference signal received power
RSSI	received signal strength indicator
SON	self-organizing networks
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TTLS	Tunneled Transport Layer Security
UE	user equipment
USIM	Universal Subscriber Identity Module
WIC	Wi-Fi controller
WLAN	wireless local area network

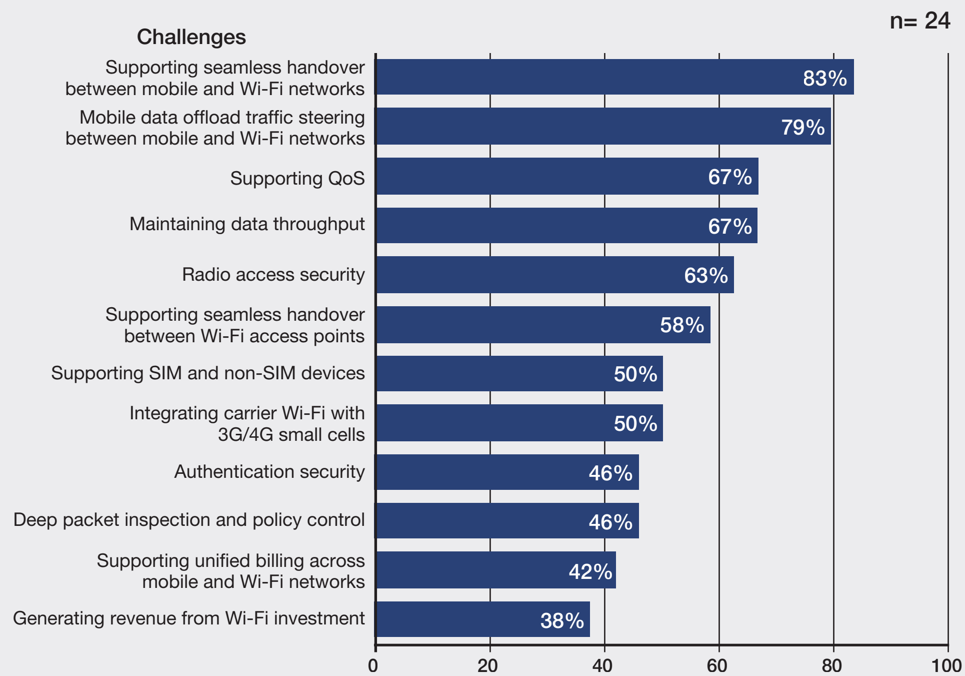
The results of a survey[1] carried out with 24 service providers are illustrated in Figure 1. These highlight the challenges operators are focusing their attention on when it comes to carrier Wi-Fi deployment.

Some steps have already been taken to include Wi-Fi in mobile broadband solutions, such as EAP authentication. Some solutions are already supported by UEs, while others will be available shortly. But much more can be done.

With these challenges in mind, the top three priorities for next generation carrier Wi-Fi are:

- traffic steering 3GPP/Wi-Fi – to maintain optimal selection of an access network so quality of experience can be ensured and data throughput maintained;
- authentication – to provide radio-access network security for both SIM- and non-SIM-based devices; and
- DPI, support for unified billing and support for seamless handover – achieved by integrating with the core infrastructure already deployed for 3GPP access.

FIGURE 1 Mobile and Wi-Fi network integration: the main challenges



When the varied set of resources in a heterogeneous network can be combined and optimized, networks can provide increased capacity and the performance needed to give subscribers the desired level of user experience. So for Wi-Fi, the objective is not to turn it into a 3GPP technology, but rather to figure out how to add 3GPP intelligence and control over Wi-Fi usage, so that all resources are used in an optimal way while delivering the best user experience. When Wi-Fi becomes just another RAT, the synergies and application of mobile network capabilities, intelligence and infrastructure will remove the burden from Wi-Fi to meet all of the challenges outlined in Figure 1.

With the operator in control, and with Wi-Fi networks that are integrated with mobile radio-access and core networks, subscribers will experience high-performing mobile broadband that operates in a harmonized way. Operators will be able to control, predict and monitor the choice of connectivity, allowing them to optimize both the user experience and resource utilization across the entire network.

Traffic steering 3GPP/Wi-Fi

In a heterogeneous network, the type and amount of resources that are available to provide mobile broadband are quite diverse, as networks are built using:

- multiple technologies including GSM, WCDMA, LTE and Wi-Fi;
- several types of cells including macro, small cells and APs; and
- varying network capabilities including carrier aggregation; different carrier bandwidths; 802.11n; and 802.11ac.

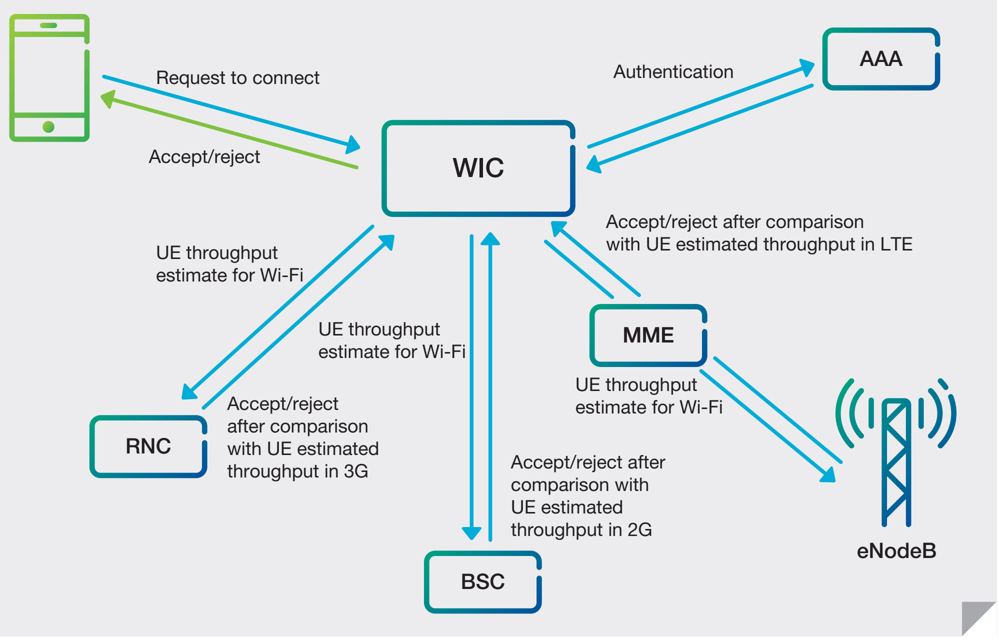
To provide the best user experience across all available resources and optimize resource utilization, the decision of whether or not to switch to Wi-Fi or back to cellular, and when to switch, needs to be made according to a more complex set of principles than simply: if there is an available Wi-Fi with adequate signal strength, then switch to it. The decision should take into account all available technologies and carriers, all visible cells, network and UE capabilities, radio conditions for each specific UE (which requires decisions to be made in real time, as these conditions fluctuate rapidly), and should ultimately be based on a calculated performance estimate for each UE, given the aggregation of all terminals in the area.

In a heterogeneous network it is more desirable to move users to different technologies, carriers and layers. And so, real-time coordination of all resources adds an additional layer of complexity to the Wi-Fi/cellular decision.

For example, if we assume that the overall goal is to obtain the best UE throughput (as this has a direct impact on user experience), UEs that have 3GPP carrier aggregation capabilities should switch to Wi-Fi much later than terminals that don't.

In another scenario involving three UEs, the best solution is to assign the first UE to a coordinated macro/small cell to deliver higher throughput, to assign another 3GPP technology or carrier to the second UE, and to allocate a Wi-Fi access point to the third device – as this UE has 802.11ac capabilities and a good radio link budget in Wi-Fi. Good coordination is required to make

FIGURE 2 Concept of a performance-based mobility feature



such a decision, where the best solution is attained for all three UEs given their individual requirements and those of the other two devices.

The ability to assure predictable and consistent switching behavior in heterogeneous network architectures eases network planning, makes optimal use of available resources and ensures good performance for all subscribers independent of device. This implies that a Wi-Fi/cellular decision-making mechanism needs to be independent of UE type, UE operating system and UE vendor.

Crystal ball

As good predictions can prevent UEs from switching too often from one RAT to another, the ability to forecast network states and available capacity is a fundamental tool for the RAN to operate effectively and to help improve the mobile broadband experience. Avoiding the ping-pong effect is beneficial because the less switching among RATs, the fewer the signals between the RAN and the core, and the less the impact on battery consumption in the terminal.

The RAN is the best place in the network to measure available resources for specific UE forecasts, as it has a complete overview of resources, knowledge of the distributed SON features, information about potential mobility decisions, as well as an awareness of all UEs in the area.

For years, operators have deployed mobility features both within and between 3GPP radio access networks that allow the network to determine in what cell, with which carrier or by what technology a UE should be hosted. These features make good use of all available resources to provide everyone connected to the network with an optimal mobile broadband experience. Decisions are made by the network on the basis of the available resources, radio conditions of UEs and the current state of the network (an aggregation of information from the network and all the UEs in the area).

A mobility feature

Ericsson's concept of a mobility feature for switching to and from Wi-Fi provides operators with the capability to control when UEs connect to Wi-Fi and when data traffic should be switched back to 3GPP – based on the forecasted performance for the specific UE.

By deploying a mobility feature that is based on performance, operators will be in a position to add Wi-Fi to their mobile broadband resources, just like any another RAT. And as the same entities make the decisions about 3GPP mobility, 3GPP/Wi-Fi mobility and distributed SON features, decisions are coordinated, preventing devices from looping, and improving resource utilization as a result of less signaling.

To ensure that the benefits of a mobility feature supporting real-time traffic steering can reach mass market quickly, such a feature needs to be developed to work on legacy UEs without the need to install a client. To achieve this and to avoid placing additional requirements on UEs that would delay the applicability of the feature, an interface needs to be placed between the controllers – BSC, RNC, Wi-Fi controller (WIC) and MME – of the different technologies. Switching decisions need to be made jointly by these controllers, as illustrated in Figure 2 – a simplified flow diagram for a performance-based mobility feature.

To illustrate how the concept works, it may be useful to consider the case of a UE that is moving closer to an operator AP, but is currently hosted in a 3G cellular network:

- the default UE behavior is to request a connection to the Wi-Fi on detection of the AP;
- the WIC will proxy the authentication request;
- on authentication, the WIC provides the RNC currently hosting the UE with an estimated performance for the UE in Wi-Fi;
- if the 3G throughput estimation is higher than the estimates for Wi-Fi, the RNC will order the WIC to reject the connection, thus maintaining data transmission over 3G.

As long as the UE is in the vicinity of the AP, the connection manager in the UE will keep trying to connect to the Wi-Fi, allowing the network to decide to switch when and if the conditions become more favorable in Wi-Fi.

Once a client is accepted into the Wi-Fi access network, the UE throughput in Wi-Fi and the estimated throughput for the UE in the NodeB are monitored continuously. When NodeB throughput surpasses Wi-Fi performance for the UE, it is disconnected from Wi-Fi and data communication will switch back to 3G.

Adding smartness

In addition to guaranteeing the best experience for users and optimizing use of resources, maintaining control over the Wi-Fi/cellular switching process provides operators with a platform that can be rapidly adapted to include additional parameters. For example, operators will be able to include subscription parameters or service considerations into the switching decision, without having to wait for support to be implemented by all UEs.

The real-time switching decision has a greater impact on user experience for UEs that are in connected mode. Consequently, an extension of existing mobility features for connected mode that includes support for Wi-Fi would optimize and enhance this decision. This could be achieved by including Wi-Fi parameters in UE measurement reports (which currently include only cellular measurements) and so further standardization and extension of mobility mechanisms is foreseen.

The way these measurements would be handled by the UE is illustrated in Figure 3, and the suggested traffic-steering process would work as follows:

1. the RAN instructs the UE by setting thresholds or conditions on which UE should perform measurement reporting. For example, the RAN may provide a condition based on signal strength – RSSI – broadcasted WAN metric and load or received power – RSRP;
2. if any of the thresholds are met, the UE reports WLAN measurements back to the RAN;
3. on the basis of this information, the current network state and any other information it has available, the 3GPP RAN will send a traffic-steering message to the UE to switch data traffic to or from WLAN.

The 3GPP mobility mechanisms for idle mode will be extended in 3GPP Rel-12, providing coordination between 3GPP and Wi-Fi for UEs in idle mode.

While the suggested mobility feature can evolve to include enhancements, it can be included in any vendor solution without requiring any direct interfaces, thus increasing the level of coordination between the various access networks, cell types and carriers from different vendors.

Traffic steering today – limitations

Today, the decision to move traffic between 3GPP and Wi-Fi is made independently by each UE based on the UE's implementation of the connection manager. With varying implementations, UEs from different vendors are likely to carry out the switching decision at different times. This makes the ecosystem unpredictable, increases capex and opex and limits the operator's ability to guarantee superior user experience.

The algorithm currently used by UEs is oversimplified: the selection of Wi-Fi over cellular is based solely on the availability of Wi-Fi. Once a UE detects Wi-Fi, it automatically shifts data traffic to it. Even if devices become smarter, UEs will still make decisions based on a single cell and a single AP – decisions that are not coordinated with the network (which can see all resources) or with other UEs in the area. Most of the UEs in the coverage area of an AP will therefore try to connect to it.

What is Wi-Fi good at?

Let's consider how Wi-Fi is designed: to provide high peak rates and low latency for a limited number of users in the vicinity of an AP. When too many users are connected, or when the users have bad link budgets, the performance of the carrier sense multiple access (CSMA) protocol degrades and the total capacity of the AP drops rapidly.

To avoid this type of degradation, an AP should not permit a UE to attach unless the following conditions are met:

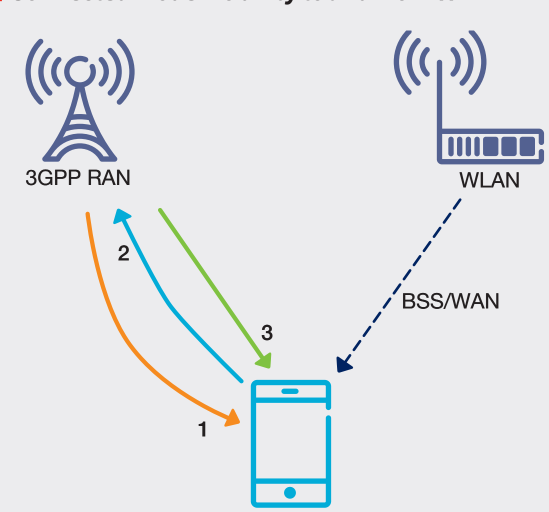
- the service level provided to the UE over Wi-Fi is better than the level offered over cellular; and
- the quality of the Wi-Fi connection is good enough to ensure that the experience level for users that are already connected to the AP will not be overly affected by the addition of another user.

Proof of concept

By putting the network in control, and using all the network information and aggregated information from UEs in the decision-making process, the network can provide the best user experience as well as increasing its overall mobile broadband capacity. The proof of concept measurements for such an approach are shown in Figure 4.

The left-hand graph shows that by rejecting users with bad link budgets and poor radio conditions, the APs can deliver higher throughput rates with exactly the same equipment. Without the mobility feature, the AP reaches a maximum peak rate of 30Mbps,

FIGURE 3 **Connected mode mobility to and from Wi-Fi**



and delivered throughput for most of the UEs is between 0 and 17.5Mbps. With the feature activated, the same AP reaches a maximum peak rate of 40Mbps, with most users receiving between 20 and 40Mbps, and the capacity is increased up to 100 percent.

The right-hand graph shows that without the mobility feature, UE performance drops by up to 20Mbps; 50 percent of users experience a drop of 10Mbps and all of them experience inferior performance when moving to Wi-Fi. With the feature activated, the throughput difference in the worse case is 7.5Mbps and on average the difference is zero – thus mobile broadband experience is maintained.

Network probing

Another approach to optimizing connections is to force the UE to probe the network before it switches. However, this approach increases the uncertainty of measurements – the greater the number of UEs probing the network, the more unrealistic measurements become. Probing can at best provide an indication of the level of performance available at a given moment, and results cannot take into consideration changes to network parameters created by SON features, triggering of mobility features or resource utilization by other UEs. The lack of coordination among individual UEs and the decisions made can lead to devices ping-ponging from one access technology to another, causing signaling storms and additional battery consumption – leading to a degradation in overall network performance.

Many implementations

The variety of connection manager implementations in UEs and the range of radio sensitivities means that the outcome of today's oversimplified mobility mechanism is unpredictable, which makes it difficult for operators to plan and optimize networks.

Approaches working against each other

Today, 3GPP mobility features are deployed both within a radio access technology and among technologies. These features are controlled by the RAN, and work in real time to provide the desired mobile broadband experience and optimize resource management. They also take into account network parameter changes, as SON features are triggered to adapt network behavior to constantly changing subscriber activity.

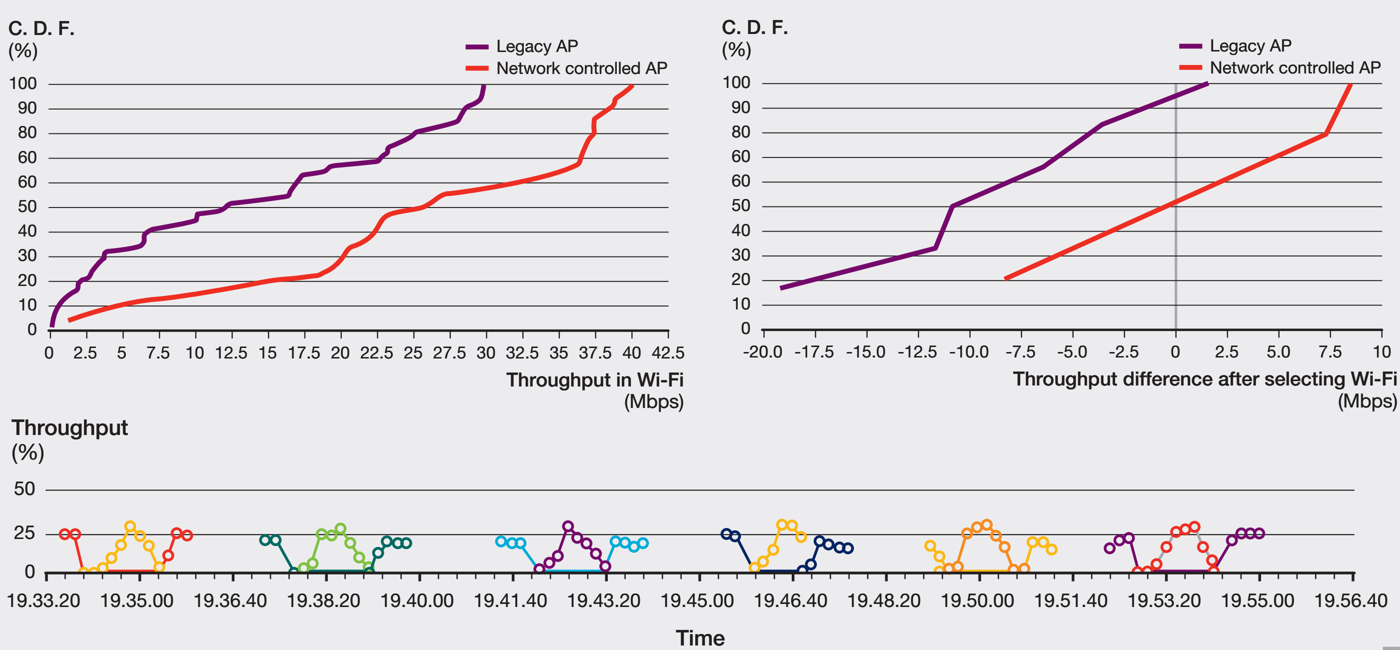
If the 3GPP/Wi-Fi decision continues to be made by the UE, this can interfere with deployed 3GPP mobility mechanisms, causing devices to loop among access networks and wasting resources. For example, an active 3GPP mobility feature might be in the process of switching a UE to another technology (from LTE to 3G, for example) when the device decides to switch to Wi-Fi instead. If the Wi-Fi becomes overloaded, it will switch the UE back to the 3GPP network, which might trigger an additional switch to another cell.

Integration tools

Some complementary tools, such as Hotspot 2.0 and ANDSF, have been developed to ease the integration of Wi-Fi.

By using HS2.0, broadcasted BSS load and WAN metrics, UE-based switching improves somewhat[2], as these mechanisms can prevent UEs from connecting to overloaded or limited backhaul Wi-Fi APs. However, a low load does not necessarily imply that the resource availability of an AP is good. Low load can be caused by a bad radio environment

FIGURE 4 Measured capacity increase by RRM and coordination of Wi-Fi and 3GPP



due to interference. To use these mechanisms efficiently, the refresh frequency of broadcasted load update needs to be fine-tuned to prevent mass toggling between cellular and Wi-Fi accesses as a result of brief load peaks.

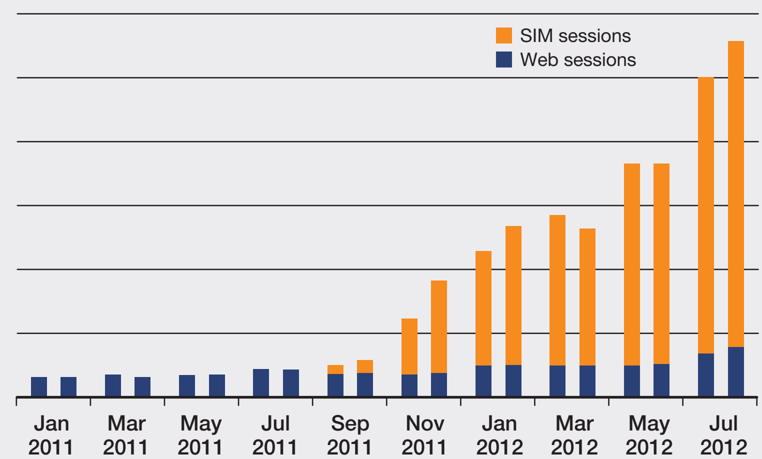
The ANDSF mechanism augments PLMN selection, providing operators with improved control over the decisions made by devices. Through a set of static operator-defined rules, ANDSF guides devices through the decision-making process of where, when and how to choose a non-3GPP network. But the final decision is still made by the UE and is still dependent on the implementation of the device's connection manager. ANDSF is defined to take into account the local environment, in other words, the specific connection manager implementation in the UE, and so UEs from different vendors behave in different ways, and using ANDSF might lead to an unpredictable outcome.

Even if they are enhanced with radio information, NAS-based solutions do not have the real-time information needed to make the optimal decision. This is because requirements on information updates would become too demanding for terminals and networks.

The ANDSF mechanism is, however, valuable as it provides operators with some level of control over the 3GPP/Wi-Fi selection process, and it takes into account static or slowly changing network parameters. However, this mechanism has an impact on battery utilization in UEs, as it scans continuously for Wi-Fi and does not cater for the rapidly fluctuating RF environment experienced by a mobile device. Neither does the mechanism take into account UE and radio access capabilities (such as LTE, HSPA, EDGE, carrier aggregation, cell bandwidth, 802.11n and 802.11ac), or network changes (as a result of self-optimizing features in RAN). And it does not provide real-time coordination with decisions in other UEs in the area.

By deploying an HS2.0- and/or ANDSF-only approach, the same policy will be applied by all UEs configured with that policy, independently of their RF conditions, cell and network capabilities in a manner that is not coordinated with other UE decisions or network

FIGURE 5 **Usage of Wi-Fi shown by authentication method**



features. This results in an inability to guarantee the best user experience as well as creating additional opex and capex for the operator, as resource utilization is not optimized on a network level.

Scenario: many users on a train

Consider this scenario: a train on which 200 UEs have ongoing mobile broadband sessions enters a station where two APs are deployed. The APs in the station perform best when the number of UEs attached is less than 20. If AP1 has a slightly better signal strength than AP2, it is possible that 180 of the UEs on the train will try to connect to AP1, while the remaining 20 UEs will select AP2. This is because each UE is ignorant of the decisions made by all the other UEs. Subsequently, a number of UEs connected to AP1 will be steered to AP2 or back to 3GPP as a result of the high load on AP1.

When two UEs apply the same policy, the one that supports carrier aggregation should move data traffic to Wi-Fi much later – which requires coordination.

So while ANDSF can be used as a simple mechanism for offloading, it neither guarantees the best user experience nor optimal resource utilization.

Seamless authentication and increased security

To secure the air link between a UE and a hotspot, Passpoint devices use the WPA2 Enterprise security protocol. WPA2 is a four-way handshaking protocol based on AES encryption, offering a level of security that is comparable to cellular networks.

The Hotspot 2.0 specification supports four commonly deployed standard protocols:

- SIM-based authentication – EAP-SIM for devices with SIM credentials and EAP-AKA for devices with USIM credentials; and
- non-SIM-based authentication – EAP-TLS for client and server-side authentication, with a trusted root certificate, and EAP-TTLS with MS-CHAPv2 for user-name-password authentication.

The Hotspot 2.0 specification complements WPA2 Enterprise security by incorporating features, such as layer-2 traffic inspection and filtering, as well as broadcast/multicast control, which are often used to mitigate common attacks on public Wi-Fi deployments.

Seamless authentication (where users are not required to introduce a user name and password) and increased security are key to Wi-Fi usage. This phenomenon is illustrated in Figure 5, which shows the uptake of Wi-Fi in an airport network enabled with EAP-SIM/AKA authentication.

By reusing SIM mechanisms, subscribers only need to be provisioned once in the HSS/HLR to use an operator's mobile broadband.

Core integration and IP session mobility in 3GPP/Wi-Fi

Connection to the mobile core networks from Wi-Fi equipment gives subscribers direct access to operator services, and provides operators with a mechanism to improve visibility, reuse their mobile broadband infrastructure, and integrate with different systems (LI, DPI, session establishment and management, policy decision and enforcement, reuse of wholesale and roaming agreements, access to operator branded or hosted services, and online and offline charging). Such an architecture provides a harmonized platform for handling cellular and Wi-Fi access, allowing Wi-Fi to become a continuation of the operator's mobile broadband experience.

Packet-core network integration helps operators to gain control of non-cellular traffic, and consequently of the user experience.

Seamless handover – uninterrupted IP session mobility between Wi-Fi and 3GPP – is a key technology when it comes to providing good user experience and mobility. To implement it, Ericsson has taken a leading role in both the standardization process and in product development.

In 3GPP Rel-11, the GPRS Tunneling Protocol (GTP) – which is widely deployed in mobile networks – was specified for the S2a interface. Use of this interface, for trusted non-3GPP access, makes it possible for UEs to connect to the Wi-Fi network and utilize packet-core network services without mobility or tunneling support in the UE. The S2b interface was also included in the standard for connection to the core through untrusted Wi-Fi.

3GPP Rel-12 standards will enable GTPv2-based IP session mobility between Wi-Fi and 3GPP over the S2a interface. Ericsson together with Qualcomm demonstrated how this works at MWC 2013, and IP session mobility is expected to appear in vendor products in 2014.

The Rel-12 solution will bring the user experience even closer to mobile broadband by overcoming the limitations of two IP stacks (one for cellular and one for Wi-Fi) used in current UE implementation. The double stack approach results in IP address reallocation every time devices move between cellular and Wi-Fi.

Some applications have tried to overcome these limitations by deploying tunneling mechanisms and using buffers, so that users do not notice the delay introduced in the session by the IP address reallocation (reestablishment of TCP sessions, socket reallocation, packet loss and rerouting delays). But these solutions are not optimal for real-time applications such as video streaming or voice calls; nor do they support IP-address-dependent security mechanisms such as VPN services, and they are not supported by enough UEs to be mass-market. By moving the support for IP address continuity to the modem, it is possible for a device to keep its IP address at handover in a way that is completely transparent to applications. This is what 3GPP Rel-12 offers.

Conclusion

Next generation carrier Wi-Fi addresses the technical challenges relating to mobile broadband Wi-Fi. By enabling operators to add Wi-Fi capacity where 3GPP spectrum is scarce, Wi-Fi-based business models can be included into operator offerings to maintain optimal mobile broadband experience.

With operators in control and Wi-Fi integrated into heterogeneous networks, the mobile broadband experience will become harmonized and provide users with the best possible performance. By taking control, operators will be able to predict and monitor the choice of connectivity, maintaining the user experience and optimizing network resource utilization.

Ericsson will develop its 3GPP and Wi-Fi portfolios based on the concepts outlined above.

Ruth Guerra

joined Ericsson in 1999 and is currently strategic product manager for Wi-Fi integration at Product Line Wi-Fi and Mobile Enterprise. She is an expert in Wi-Fi and 3GPP networks, focusing on the strategic evolution of Wi-Fi and 3GPP RAN integration. She holds an M.Sc. in Telecommunications from the Technical University of Madrid (Universidad Politécnica de Madrid), Spain.

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Address:
Telefonaktiebolaget LM Ericsson
SE-164 83 Stockholm, Sweden
Phone: +46 8 719 0000
Fax: +46 8 522 915 99

Web:
www.ericsson com/review

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Deirdre P. Doyle
deirdre doyle@jgcommunication.se

Chief subeditor:
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Art director:
Carola Pilarz

Illustrations: Claes-Göran Andersson

Telefonaktiebolaget LM Ericsson
SE-164 83 Stockholm, Sweden
Phone: + 46 10 719 0000
Fax: +46 8 522 915 99

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