©ISTOCKPHOTO.COM/KEITH BISHOP

Mobile-Edge Computing Architecture

The role of MEC in the Internet of Things.

By Dario Sabella, Alessandro Vaillant, Pekka Kuure, Uwe Rauschenbach, and Fabio Giust

IMAGE LICENSED BY INGRAM PUBLISHING

Mobile-edge computing (MEC) is an emerging technology currently recognized as a key enabler for 5G networks. Compatible with current 4G networks, MEC will address many key uses of the 5G system, motivated by the massive diffusion of the Internet of Things (IoT). This article aims to provide a tutorial on MEC technology and an overview of the MEC framework and architecture recently defined by the European Telecommunications Standards Institute (ETSI) MEC Industry Specification Group (ISG) standardization organization. We provide some examples of MEC deployment, with special reference to IoT cases, since IoT is recognized as a main driver for 5G. Finally, we discuss the main benefits and challenges for MEC moving toward 5G.

BACKGROUND

The path toward defining 5G systems encompasses all the requirements of the communication network to cope with traffic needs so as to allow operators to offer services and provide contents efficiently and profitably.

While 4G networks have been driven by the need to deliver video content, the

Digital Object Identifier 10.1109/MCE.2016.2590118
Date of publication: 22 September 2016

2162-2248/16©2016IEEE

coming years will also witness the explosion of machine-to-machine (M2M) connections [1] due to the increase of IoT traffic and services, which will be dominated by several new vertical business segments [2], e.g., automotive and mobility, factories of the future (sometimes referred also as Industry 4.0), health care, media and entertainment, and energy.

With this view, the emerging scenario (depicted in Figure 1) will be characterized by heterogeneous terminals and devices and also content and traffic types (including legacy voice and data traffic, as well as those generated by emerging M2M connections), all with different quality-of-experience (QoE) requirements. In this 5G scenario, both research projects and standardization bodies are currently considering MEC with increasing attention, especially as a key enabler for new emerging uses that will need to be properly managed at the edge of the network.

MEC technology, recently introduced by the ETSI ISG on MEC [3], offers cloud-computing capabilities within the radio access network (RAN) and an information technology service environment at the edge of the mobile network, close to mobile subscribers. This environment is characterized by ultralow latency, high bandwidth, and real-time access to radio network information that can be leveraged by applications and QoE optimization platforms. Edge may refer to both the base stations themselves [e.g., evolved node B (eNB), radio network controller (RNC), etc.] and data centers close to the radio network (e.g., located at aggregation points). Operators can open their RAN edge to authorized third parties, allowing them to deploy innovative applications and services toward mobile subscribers, enterprises, and vertical segments, flexibly and rapidly. MEC will bring significant benefits not only for operators but also for third parties and over-the-top (OTT) companies that will have the opportunity to run their applications at the edge of the mobile network, close to mobile subscribers (with related new business opportunities). Finally, the common consumer may also experience improved performance and new services offered by the MEC system.

MEC FRAMEWORK AND ARCHITECTURE

ETSI MEC ISG was launched in December 2014 and tasked to produce a set of specifications to enable hosting of third-party-provided applications in a multivendor environment. Ever since, the ISG has been working on specifications, starting from the examples to define the requirements and followed by the definitions for the architecture. The work was tasked to last for two years, and the ISG MEC has already published the foundation specifications on technical requirements and reference architecture. The ISG has proceeded to the next stage to specify the application enablement platform, the mobile-edge (ME) services, and the needed application programming interfaces that the ME applications can use to provide a whole new range of services with enhanced end-user experience.

The work on architecture has thus been finalized, and the ISG has defined the framework and reference architecture [7] for MEC, as described in the following section.

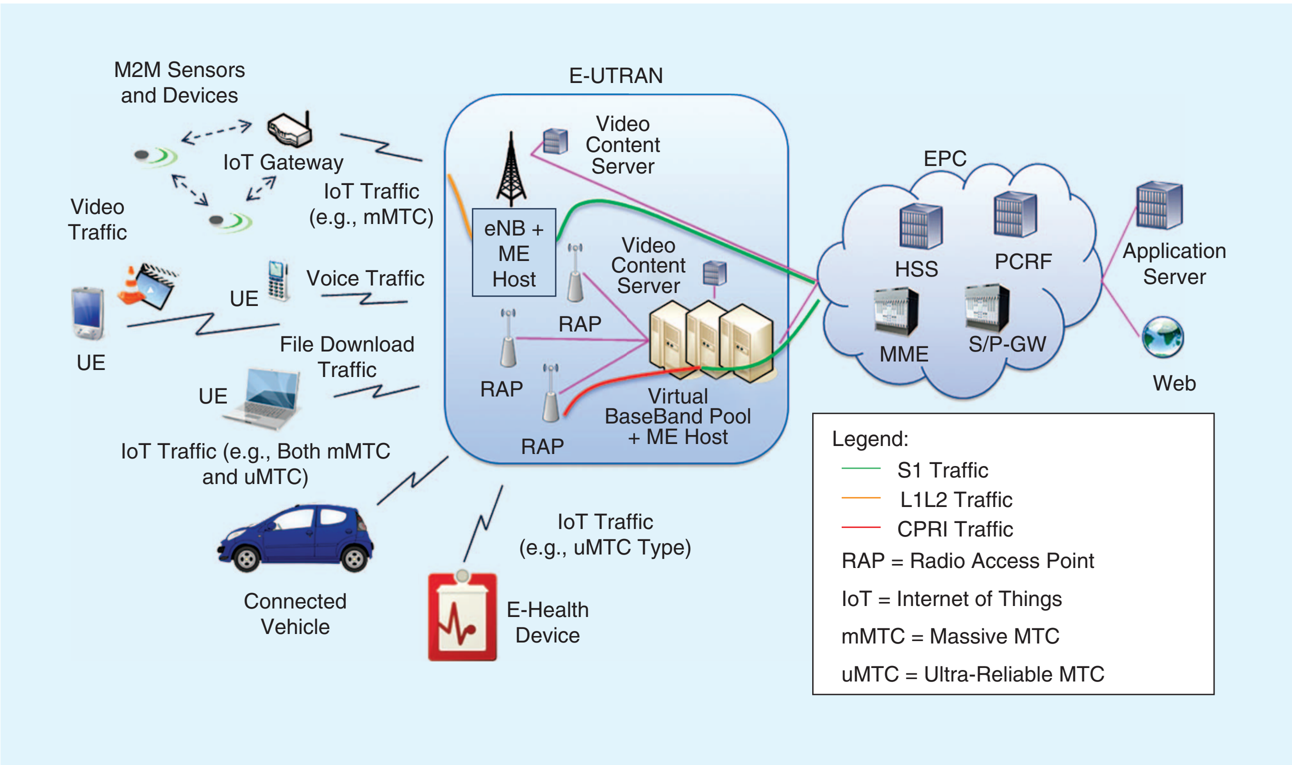

FIGURE 1. The MEC and the 5G scenario.

MEC FRAMEWORK

The MEC framework, as presented in Figure 2, shows the high-level functional entities that are involved. The entities are further grouped in the system-level, host-level, and network-level entities. The ME host level consists of the ME host and the corresponding ME host-level management entity. The ME host is further split to include the ME platform, the ME applications, and the virtualization infrastructure.

The networks level consists of related external entities that are the 3rd Generation Partnership Project (3GPP) cellular network, the local networks, and the external networks. This layer represents the connectivity to local area networks, cellular networks, and external networks such as the Internet.

On top of everything is the ME system-level management that, by definition, has the overall visibility to the whole ME system. The ME system consists of the ME hosts and the ME management necessary to run ME applications within an operator network or a subset of an operator network.

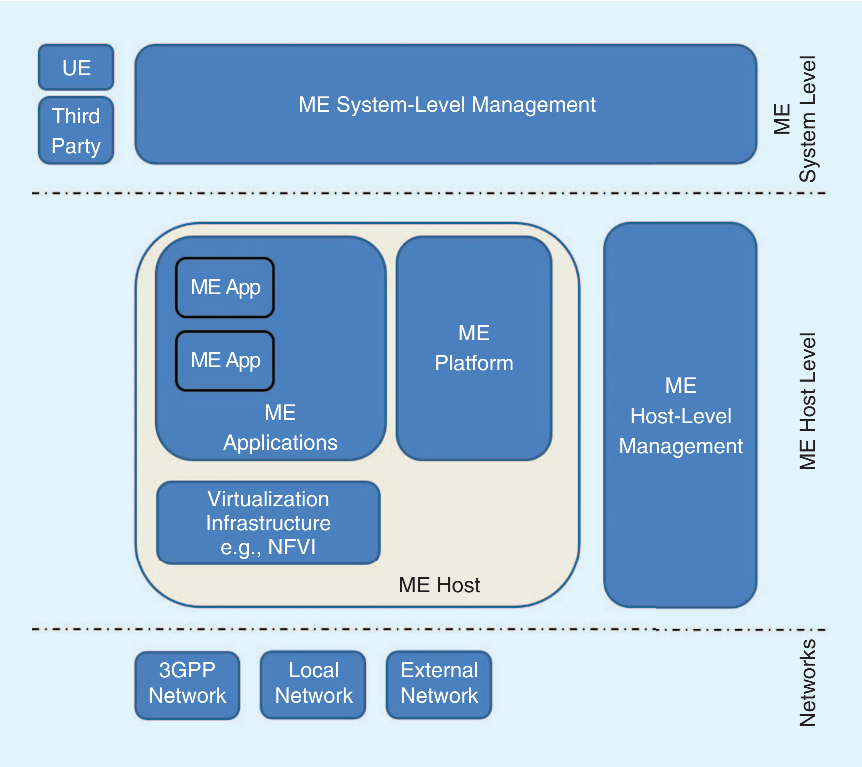

FIGURE 2. The MEC framework.

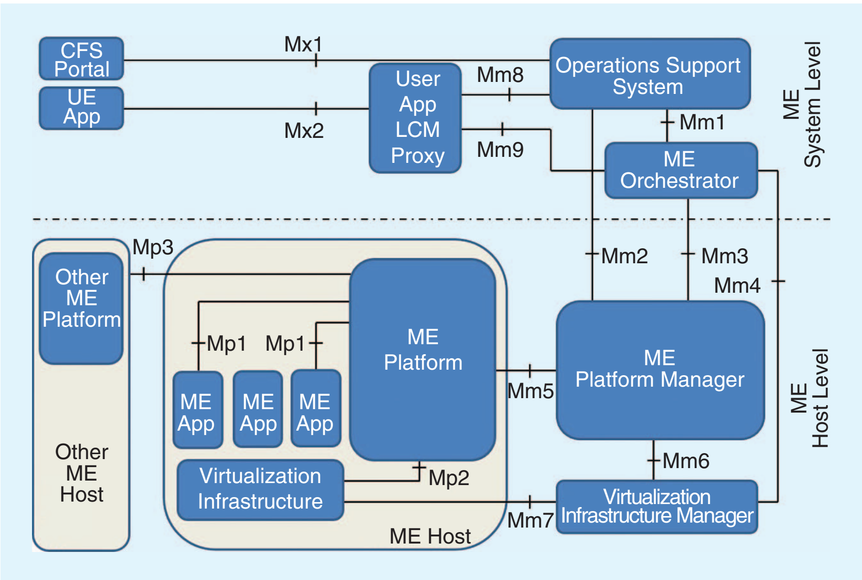

FIGURE 3. The MEC reference architecture.

MEC REFERENCE ARCHITECTURE

A more thorough understanding on ME systems can be obtained from the reference architecture (depicted in Figure 3), which defines the functional entities in more detail with their relations to each other. The reference architecture has the same split to system level and host level as the framework. The network level is not visible in the reference architecture, as there are no MEC-specific reference points needed to access those entities.

The ME host is an entity consisting of the ME platform and the virtualization infrastructure that provides computing, storage, and network resources for the ME applications. In addition, the ME host can provide persistent storage and time of day information for the applications. The virtualization infrastructure includes a data plane that executes the forwarding rules received by the ME platform and routes the traffic between the applications, services, and networks.

The ME platform represents a collection of baseline functionalities that are required to run applications on a particular ME host and to enable ME applications to discover, advertise, offer, and consume the ME services. ME services can be provided by the platform and by the applications, and both the platform and applications may consume ME services. The essential baseline functionalities of the ME platform are needed to steer the traffic between the applications, services, and networks. The ME platform receives the traffic forwarding rules from the ME platform manager, ME applications, and ME services, and based on those, as well as on policies, it provides the instructions to the forwarding plane. In addition, the ME platform supports configuring the local domain name system (DNS) proxy/ server, which can be used to direct the user traffic to desired ME applications. The ME platform can communicate with other ME platforms over an Mp3 reference point, which is intended for control plane procedures. Using this interface, several platforms may be grouped together and can form a communications grid.

ME applications are running as virtual machines on top of virtualization infrastructure provided by the ME host. The applications interact with the ME platform over an Mp1 reference point to consume the services offered by the platform. Applications can also offer services to the platform that can further provide those to other applications. The Mp1 reference point is also used for additional support procedures such as to indicate the application availability or to prepare to relocate the application state for the user in case of handover events. ME applications may indicate requirements on their needed resources or services and, in addition, indicate their constraints on maximum allowed latencies. These requirements are validated in the system level, and the selection of target ME host(s) is performed based on the requirements.

An ME platform manager (MEPM) is a host-level entity that is further split into ME platform element management, ME application lifecycle management, and ME application rules and requirements management functions. The application lifecycle management consists of application instantiation and termination procedures as well as providing indication to the ME orchestrator (MEO) on application-related events. The rules and requirements management includes authorizations, traffic rules, DNS configurations, and resolving issues when a set of rules is in conflict. The reference point between the ME platform and the MEPM is used to configure the platform and the rules, to provision the traffic filtering rules, to manage the application relocation, and to support the lifecycle procedures of applications. The reference point toward the operations support system (OSS) is used for the fault, configuration, and performance management of the ME platform. The reference point between the MEO and the MEPM provides support for application lifecycle management and application-related policies and to maintain up-to-date information on available ME services in the ME system.

MEO is the central function in the ME system, as it has visibility over the resources and capabilities of the entire ME network. The MEO maintains information on the whole ME system, as it knows all the deployed ME hosts, the services and resources available in each host, the applications that are instantiated, and the topology of the network. The orchestrator is also responsible for managing the ME applications and the related procedures by supporting on-boarding the applications, checking the integrity and authenticity of the application, validating the policies for the applications, and maintaining a catalog of the applications that are available. The MEO also prepares the instantiation procedures by providing instructions to virtualization infrastructure managers on how to treat the applications. The ME applications may indicate their requirements, e.g., for the resources, services, location, and performance, such as maximum allowed latency, and it is the MEO's responsibility to ensure that the requirements are met. The orchestrator uses the requirements received from the applications in the selection process for the target ME host. If the application needs to be relocated, the MEO is the entity that triggers the procedure. The orchestrator has a reference point with the OSS that is intended for triggering the instantiation and termination of ME applications in the ME systems. The reference point toward the virtualization infrastructure manager (VIM) is used to manage the virtualized resources of the ME host and to manage the application images that are provided for instantiation. It is further used for maintaining status information on available resources. The OSS of an operator is a function that is widely used to manage various services and subsystems in the operators' network.

From the ME system point of view, the OSS is the highest-level management system to assist in getting the ME applications running in the desired location of the network. The OSS receives requests to instantiate and terminate the ME applications from the customer-facing service (CFS) portal and from the clients in the user equipment (UE). Being on the boundary between the external world and operators' network, the OSS checks the integrity and authenticity of the application package and authorizes the request. The requests that are granted by the OSS are forwarded to the MEO for further processing. The OSS can also have the capabilities to relocate the applications between different cloud systems.

The CFS acts as an entry point for the third parties. This portal can be used for operations to manage the provisioning, selection, and ordering of the ME applications. Developer parties can use the portal to make their created ME applications available in the operators' ME system. Other customers such as enterprise clients may use the portal to select the applications that are of interest for them and to provide instructions when and where they wish to use the selected application. The CFS portal can also provide business-related information for customers, for example, related to service-level agreement or billing. The CFS is connected to the OSS over the reference point between the entities.

The user application lifecycle management proxy (user app LCM proxy) is a function that the ME-related clients and applications use to request services related to on-boarding, instantiation, and termination of the applications. This proxy can be used to request to relocate the application out from the ME system to the external cloud or in to the ME system from the external cloud. The access portal authorizes all the requests before proceeding with forwarding actions toward the OSS or the MEO. The user app LCM proxy can only be accessed from the mobile network. It exposes a reference point toward the applications and the clients in the UE.

> In other words, MEC will be able to provide in advance new IoT services that would not be technically or economically feasible before the launch of 5G-like networks.

The VIM is responsible for managing the virtualized resources for the ME applications. The management tasks consist of allocating and releasing virtualized computing, storage, and network resources provided by the virtualization infrastructure. The VIM also prepares the virtualization infrastructure to run software images, and the software images can be also stored by the VIM for a faster application instantiation procedure. As virtualized resources may also run out of capacity or fail in operation, it is important to monitor them. The VIM provides support for fault and performance monitoring by collecting and reporting information on virtualized resources and providing the information further to server and system level management entities. The VIM has a reference point toward the virtualization infrastructure to manage the virtualized resources. The reference point between the MEO and VIM is used for management of the application images and the virtualized resources as well as for monitoring the availability of the resources. The reference point between the MEPM and VIM is used to manage the virtualized resources for the ME applications during their lifecycle.

KEY USE CASES FOR MEC AND IoT

As anticipated, the MEC ecosystem is likely to bring significant benefit to the mobile operator (e.g., introducing QoE platforms and agile service provisioning) and third parties/OTT (for new business opportunities) but also to the common consumer that, at the end, will be able to experience services that need to rely on very accurate localization or high performance in terms of latency and available throughput. In other words, MEC will be able to provide in advance new IoT services that would not be technically or economically feasible before the launch of 5G-like networks (possibly playing the role of a vanguard player for the exploration of tomorrow's services).

Several uses are addressed by MEC and also currently considered in next-generation mobile networks and 3GPP [5] toward 5G networks. The following section describes a selection of uses identified by ETSI MEC ISG [6], and relevant for IoT scenarios.

USE CASE: SECURITY, SAFETY, DATA ANALYTICS

Security and safety have become two of the most important verticals for IoT. The developments in technology with an ever-increasing amount of data from sensors and high-resolution video cameras create the need for a scalable, flexible, and cost-economic solution to analyze the content in real time. MEC can host the analytics applications close to the source and allow for increased reliability, better performance, and significant savings by processing huge amounts of data locally. Enhanced video analytics enables creating and using rules for different events to trigger alerts and forwarding actions. Real-time video analysis can be used to identify and classify objects (person, specific object), create rules for observation areas of interest, define and use event-based rules (entering/exiting area, leaving/removing object, loitering), and counting objects (number of people, objects). The analytics can be further enhanced by sound analytics and additional information from external sources and sensors. MEC enables an automated, flexible, scalable, and cost-efficient solution for security. Analytics function can provide flexible extensions to third parties through plug-in integration. The solution is flexible to deploy by enabling the video processing and analytics application running at an optimum location based on technical and business parameters.

USE CASE: VEHICLE-TO-INFRASTRUCTURE COMMUNICATION

Digitalization of the services is progressing with enormous speed, and the automotive sector is one area where the new technologies are shaping the whole industry. Self-driving cars have been already demonstrated by both traditional automotive and new Internet players, and it is anticipated to have the first autonomous cars commercially available by 2020. The work on a future 5G system is currently being conducted by various organizations globally, and the digitalization in the automotive industry is clearly reflected in the uses and the requirements. The IoT is a key driver for the next-generation technology, and most of the uses appear to focus on connected cars.

Connected cars are not only about self-driving capability; many other uses exist. More generally, all cases related to smart transportation are of course in strict relation to the already mentioned IoT paradigm. These cases are not only considered from a theoretical point, of view, but also early experimental activities are already currently taking place. One example is road safety service, where traffic alerts can be used by both human drivers and autonomous cars. A traffic alert service has been demonstrated in Germany at Digital A9 Motorway test bed (https://www.telekom.com/media/company/293064), where the live long-term evolution (LTE) network from Deutsche Telekom was used to carry alert messages between vehicles in the same area. The exercise was enabled by an MEC solution to achieve below 20-ms latencies vehicle-to-vehicle via the cellular infrastructure.

With the next-generation system, the latency requirements are set to the 1-ms range to allow for a wide range of use cases. MEC is the ideal solution and has been identified as a key component to support these ultralow latency scenarios as it enables hosting applications close to the users at the edge cloud and therefore provides the shortest path between the applications.

CASE: COMPUTATION OFFLOAD INTO THE EDGE CLOUD

Applications running on mobile terminals may want to offload parts of the computations into the cloud for various reasons, such as availability of more computing power or of specific hardware capabilities, reliability, joint use of the resources in collaborative applications, or saving bitrate on the air interface. The computation offload is particularly suitable for IoT applications and scenarios where terminals have limited computing capabilities, i.e., in those cases where M2M devices have severe low-power requirements, to guarantee the long lifetime of batteries. Such offload may happen statically (server components are deployed by the service provider proactively in advance) or dynamically (server components are deployed on demand by request from the UE). Also, in this case, applications benefit from the low delay provided by MEC.

REQUIREMENTS

To realize the MEC uses (and in particular those listed above), a number of requirements need to be fulfilled by an ME system and have been identified [6]. An ME system needs to provide the following capabilities:

- route network traffic from and to applications that may inspect and modify it (authorization required) and influence DNS resolution accordingly
- provide up-to-date radio network information
- allow ME applications to provide and consume ME services, including service registration, service subscription, and service announcement and support the authorization per application to provide and consume information and services
- support bandwidth management
- support user identity mapping
- provide support for mobility procedures
- provide support for running a ME application in a place that is optimal with respect to resource usage and delay figures
- provide a virtualization environment to run ME applications
- allow instantiating a ME application per request from a handset (UE).

Note that not all MEC deployments have to fulfill all the requirements defined above. As a consequence, MEC performance will be tailored to the specific deployment scenario to meet the requirements of the different uses to be supported.

HOW TO USE MEC FOR IoT CASES

An ME host is a privileged location to run applications with sensitive real-time requirement, given its proximity to where relevant part data traffic is generated and delivered. This feature is foreseen to be hugely exploited in the context of the IoT ecosystem, as "by 2018, 40% of IoT-created data will be stored, processed, analyzed, and acted upon close to, or at the edge, of the network" [4]. An ME system enables IoT applications to be installed in an operator's radio access premises, benefitting from broadband mobile radio access, as well as from reduced latency.

MEC IN AN IoT DEPLOYMENT FOR SURVEILLANCE AND SAFETY

The interplay between MEC and the IoT concepts finds a straightforward application when it comes to uses that require intensive computational load, e.g., video surveillance and object recognition. Computing-hungry algorithms for image processing can leverage the ME host's computing resources and low communication delay to meet the overall latency budget imposed by real-time automated surveillance. The above case is further developed in the following and illustrated in Figure 4.

A local network of IoT sensor devices, e.g., video cameras, is connected to the broadband mobile network (e.g., an LTE network) through the local IoT gateway. The video streams are conveyed to the ME host, where the IoT application for video surveillance is running. There, the real-time video processing is carried out so that, when an anomaly in the recorded video is detected, the IoT surveillance application sends a trigger to the central station located in the Internet. This configuration prevents deploying costly dedicated equipment and connectivity infrastructure by simply leveraging the RAN and ME system from the mobile network operator.

MEC FOR IoT DEVICES' CAPABILITIES OFFLOAD

Similarly to the one described above, many other scenarios involve mainly static nodes, where mobility support is not a primary need. Some examples embrace smart meters for water and electricity supply monitoring and sensors for home and industrial automation, as well as others, that, even if they may communicate using a wireless link, are installed in fixed locations. Given the constrained capabilities of such devices, the data processing entities and the controllers are deployed on the ME host and run as ME applications. By leveraging the rich features offered by the mobile-edge management system, such applications can be easily instantiated, relocated, and upgraded when necessary.

From a deployment perspective, the ME platform hosting the IoT applications, described here and in the previous paragraph, may sit on an entity in the RAN (e.g., eNB, RNC, or

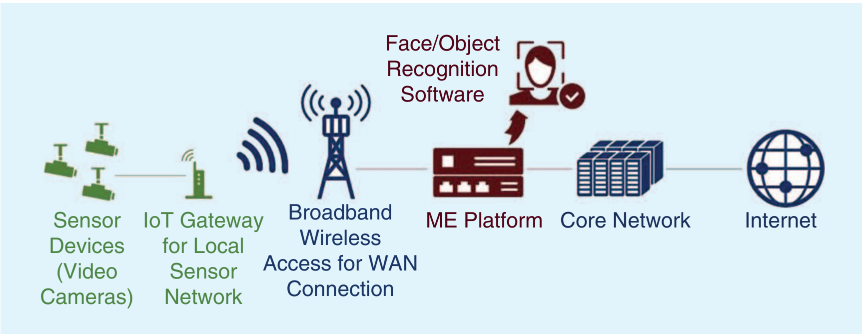

FIGURE 4. The MEC-based video surveillance. The S1-U deployment option.

on an RAN user plane interface (e.g., S1-U). In this deployment option, the ME platform is able to divert data traffic from the standard RAN user plane to the ME applications without major impact on the rest of the mobile network elements. As an example, in an evolved packet system (EPS)-based mobile network, this deployment option would imply rerouting part of the general packet radio service (GPRS) tunneling protocol-encapsulated packets flowing through the S1-U interface to the desired ME applications, as illustrated in Figure 4.

MEC FOR CONNECTED VEHICLES AND MOVING IoT DEVICES

Other relevant IoT uses require the devices to connect to the broadband mobile network and also to be able to move across different cells with mobility and session continuity support. This can be the case of IoT systems utilizing drones, road vehicles, and trains, just to mention a few. Under such circumstances, the MEC deployment option illustrated before poses some additional challenges in terms of backward compatibility with legacy mobile network entities. In fact, mobility and session management is usually performed by the core network functions, e.g., implemented by the mobility management entity, the serving gateway, and the serving GPRS support node in the current 3G/4G networks. Bringing mobility support functions to the ME platform may have a dramatic impact on the existing architecture, as legacy components should include nonstandard mechanisms to interact with the ME platform to convey the appropriate control plane information.

Nevertheless, the industry is currently looking with more interest at distributing gateways and core functions in the network edge. Present virtualized evolved packet core (EPC) solutions enable lightweight and tailored deployment of core network functions in proximity of the network's edge to support MEC-based IoT systems. In such a deployment option, the ME platform sits on the user plane interface connecting the mobile network to the rest of the packet data networks, e.g., the SGi interface in the EPS architecture (see Figure 5). ME applications for the IoT would not require complex traffic filtering and manipulation in order to receive the desired traffic, and the ME platform can leverage on legacy network entities to carry out consistent control plane operations, e.g., for mobility, as well as other crucial aspects associated with gating, quality-of-service enforcement, charging, etc.

Moreover, the emerging and growing maturity of virtualization technologies opens new research directions aiming at integrating in the same virtualization infrastructure the radio signal processing (e.g., the cloud RAN scenario), network functions (e.g., EPC entities), and applications (e.g., IoT control systems) under the umbrella of the network function virtualization (NFV) paradigm.

THE ROLE OF MEC TOWARD 5G: BENEFITS AND CHALLENGES

5G will bring an extremely flexible and programmable system able to combine computing capabilities with high-diversity types of communications (i.e., human and machine). The resulting network will be faster and smarter, allowing for higher magnitudes of connected objects consuming less energy than today. Thus, the industry expects that 5G will provide a unified framework of reference for the IoT.

Returning to the present, we can observe that the IoT phenomenon is still at an early stage of deployment, and, probably, one of the main challenges is not (only) related to the technological maturity of the ecosystem but also to the lack of integration. The current actors of the IoT industry are, in fact, typically building their own devices with a low level of integration/interoperability with the ones of the other companies: The various devices are getting connected over different forms of connectivity, such as 3G, LTE, Wi-Fi, or other spectrum. In general, the messages are small, encrypted, and come in different forms of protocols.

So what about MEC? As recognized by ETSI, MEC can be regarded as a key technology and architectural concept for enabling the transformation toward 5G [3]. The mobile network edge environment can provide ultralow latency, proximity, high bandwidth, real-time insight into radio network and context information and location awareness, enabling early 5G uses. With regard to the IoT services scenario, MEC can play a relevant low latency aggregation point to manage the various protocols, for distribution of messages, and for the processing of analytics, combining in this way high performance with availability of local computing, thus anticipating the 5G concept.

On the other hand, there are coming challenges also associated with the success of MEC in the framework of 5G. From this point of view, MEC standardization work is still at an early stage, and tight coordination with ETSI NFV is needed to ensure the harmonization of MEC deployment inside an NFV environment (and coherence for the definition of orchestration functions in the two ISGs). This aspect is very

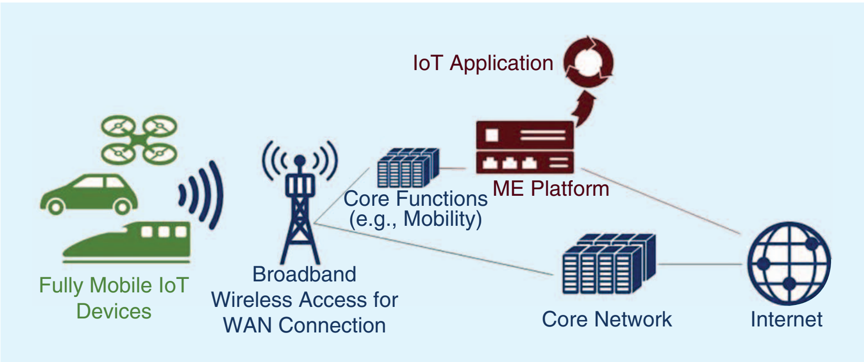

FIGURE 5. The MEC-based mobile IoT scenario. The SGi deployment option.

important not only from a standard point of view but also for the operators that are going to evaluate the opportunity to deploy MEC inside their infrastructure (whether the network is already virtualized or not). From this perspective, MEC ISG is already working in close collaboration to NFV, and it is establishing liaisons with 3GPP and other relevant standards-development organizations that will have an impact on the definition of 5G systems.

CONCLUSIONS AND FUTURE WORK

In this article, we provided a tutorial on MEC technology and an overview of the MEC framework and architecture recently defined by the ETSI MEC ISG standardization group. We described some examples of MEC deployment, with special reference to IoT uses since the IoT is recognized as a main driver for 5G. After having also discussed benefits and challenges for MEC toward 5G, we can say that MEC has definitely a window of opportunity to contribute to the creation of a common layer of integration for the IoT world. One of the main questions still open is: How will this technology coexist with LTE advanced pro and the future 5G network? For this aspect, we foresee the need for very strong cooperation between 3GPP and ETSI (e.g., NFV and possibly other SDOs) to avoid unnecessary duplication in the standard. In this sense, MEC could pave the way and be natively integrated in the network of tomorrow.

Bringing mobility support functions to the ME platform may have a dramatic impact on the existing architecture, as legacy components should include nonstandard mechanisms to interact with the ME platform to convey the appropriate control plane information.

ACKNOWLEDGMENTS

We gratefully recognize the great contributions of many colleagues, who, in fruitful cooperation, contributed with valuable insight, surveys, and vision. We would like also to thank our colleagues and delegates in ETSI MEC ISG for their support and interesting technical discussions around MEC.

ABOUT THE AUTHORS

Dario Sabella (dario.sabella@telecomitalia.it) earned his Dr.Eng. degree in electronic engineering from the Politecnico di Torino, Italy, in 2002 and his postdegree specialization master's degree in telecommunications in 2004. Since 2002, he has been with the Telecom Italia Lab, Torino, in the Wireless Innovation Department, where he is responsible for international projects for the mobile network.

Alessandro Vaillant (alessandro.vaillant@telecomitalia.it) graduated with honors in telecommunication engineering and joined TIM R&D, where he focused for nearly ten years on radio access network evolution. In 2011, he moved to the TIM Mobile Strategic Department to work on the analysis and development of new business models and products for the mobile ecosystem. He is a certified Project Management Professional and is currently enrolled in an executive M.B.A. degree program with the MIP Politecnico of Milano business school.

Pekka Kuure (pekka.kuure@nokia.com) graduated from the University of Oulu, Finland, with a degree in telecommunications and radio technologies. He is a standardization specialist at Nokia, focusing on the Internet of Things and application and services enablement in a distributed cloud environment. His past standardization activities cover a wide range of different organizations, including the 3rd Generation Partnership Project, the Internet Engineering Task Force, the Open Mobile Alliance, and the WiMAX Forum (topics on public safety, push-to-talk over cellular, and the WiMAX system).

Uwe Rauschenbach (uwe.rauschenbach@nokia.com) earned his Ph.D. degree in image coding and image transmission from the University of Rostock, Germany. He is a standardization specialist at Nokia, playing an active part in the development of industry specifications that deal with the introduction of cloud technologies to telecommunication networks [i.e., European Telecommunications Standards Institute (ETSI) Mobile-Edge Computing and ETSI Network Functions Virtualization].

Fabio Giust (fabio.giust@neclab.eu) earned his M.S. degree in telecommunications engineering from the University of Padova, Italy, and his Ph.D. degree in telematics engineering from the University Carlos III, Madrid, Spain. He is a research scientist with NEC Laboratories Europe, Heidelberg, Germany. His research interests include 5G mobile networks, distributed mobility management, mobile-edge computing, and network virtualization.

REFERENCES

[1] Cisco. (2015, May). Cisco visual networking index: Forecast and methodology, 2014–2019. [Online]. Available: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.pdf

[2] 5G Infrastructure Association. (2015, Feb.). Vision white paper. [Online]. Available: http://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf

[3] ETSI. (2015, Sept.). Mobile edge computing: A key technology towards 5G. [Online]. Available: www.etsi.org/images/files/ETSIWhitePapers/etsi_wp11_mec_a_key_technology_towards_5g.pdf

[4] International Data Corporation (IDC). (2016, Apr.). IDC reveals worldwide Internet of Things predictions for 2015. [Online]. Available: https://www.idc.com/getdoc.jsp?containerId=prUS25291514

[5] *Feasibility Study on New Services and Markets Technology Enablers; Stage 1, (Release 14)*. 3GPP TR 22.891 V14.0.0 (2016-03).

[6] *Mobile Edge Computing (MEC); Technical Requirements*. ETSI GS MEC 002 V1.1.1 (2016-03).

[7] *Mobile Edge Computing (MEC); Framework and Reference Architecture*. ETSI GS MEC 003 V1.1.1 (2016-03).