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Executive Summary

MOTO investigates the limits of 4G/LTE technologies in congested conditions and how opportunistic networking (an evolution of the Delay-Tolerant Networking (DTN) paradigm) can be used in a trustful manner to offload part of the traffic from the 4G/LTE network. Specifically, in the project view, the offloading operation on the opportunistic network formed by the users' devices will be synergic with the traffic management on the operator network and with offloading across different wireless infrastructures (such as 4G/LTE to Wi-Fi), and under the control of the operator.

In this respect the MOTO project will design, dimension, implement, and evaluate an architecture that takes advantage of the latest advances in opportunistic networking to achieve efficient *traffic offloading,* in order to help alleviate overloaded cellular infrastructures.

This document further details the MOTO approach, illustrating its target objectives and main steps.

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1.1 Introduction

This document presents the overall approach and objectives of the MOTO project.

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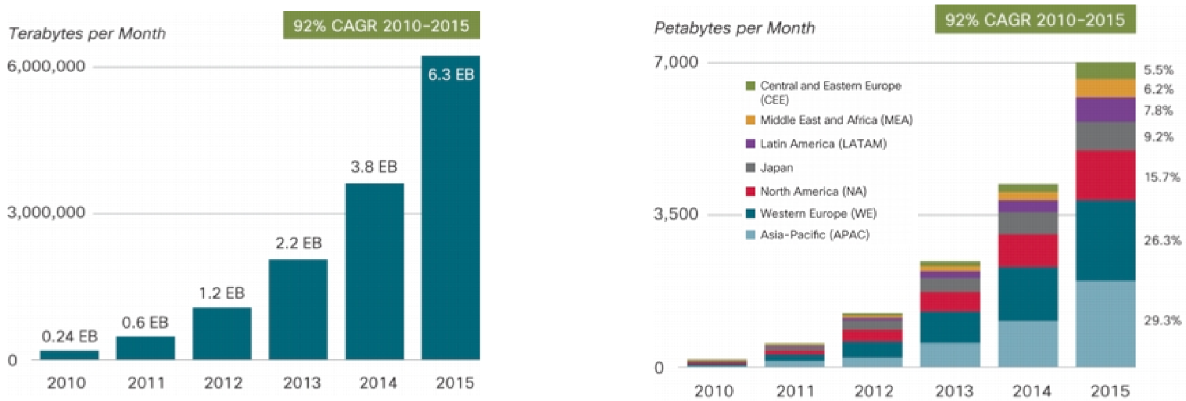
None.

2 RATIONALE

The rationale for MOTO stems from the widespread diffusion of smartphones, tablets, and other mobile devices with diverse networking and multimedia capabilities, and the associated blossoming of all kinds of data-hungry multimedia services. According to Cisco, global mobile data will experience a growth of more than 26 times in only five years for the period 2010-2015, as illustrated in Figure 1 [CVNI11].



(a) Global mobile data growth.

(b) Mobile data growth per region.

Figure 1. Mobile data forecast for the period 2010-2015 (source: Cisco VNI Mobile, 2011).

This poses dramatic challenges to mobile telecom operators all over the world. Major operators in the US [NYT09] and Europe [AT10] are experiencing severe problems in coping with the mobile data traffic generated by their users. Considerable progress is constantly made at the physical layer to increase raw bitrates, and clearly LTE and LTE advanced will help in this direction, but this is neither sufficient nor cost-efficient to accommodate all the increase in data service demand. This is because the trend of the traffic demand is exponentially increasing [CVNI11,INT09], while the improvements at the physical layer are bounded by the famous Shannon theorem and by the fact that the licensed spectrum is a limited and scarce resource [IW10]. Moreover, provisioning “additional” 4G infrastructure (even in the “lightweight version” of LTE relays) bears significant costs both at the deployment and the management phases.

As a result, it is expected that the amount of traffic generated by 4G users will be about one order of magnitude larger than the bandwidth operators will be able to deliver [INT09]. The operator will need to decide to either drastically reduce the quality of service (QoS) for all the users, or block a significant fraction of the users to provide acceptable QoS to a few. Both alternatives are largely sub-optimal and generate user dissatisfaction.

Initially, operators managed this situation using reactive, frequently unpopular, and fairly blunt instruments such as throttling and capping. More recently, there has been considerable evolution in terms of approaches to, and understanding of, how traffic can be managed optimally. The current situation requires more sophisticated approaches better aligned to optimising network performance while also meeting subscribers' needs and desires, and supporting commercial goals such as creating new revenue streams. Network and service operators are transitioning as they gain experience from an exclusively internal or operational focus (i.e., optimising network performance), to balancing these goals with commercial ones and meeting the needs of customers.

As mobile data traffic continues to rise, maintaining an adequate quality of service is becoming more challenging. This is not just due to the sheer rise in traffic, but also because today's traffic is drastically different from the one a few years ago. The type of data traffic has transitioned from basic data services (such as email or SMS) to QoS-sensitive and bandwidth-hungry applications such as video. On the network management side of the "capacity crunch" challenge, operators have a number of choices to deal with the consequences of rising data traffic and, like Russian dolls, there are yet more choices nested within each strategy. For example, they can choose to expand network capacity through upgrades; but they must then select how to do this – such as adding more cell sites, upgrading cell sites, rolling out Ethernet in the backhaul and so on. Furthermore, these choices are also dependent on commercial, regulatory, operational, and customer-related factors such as the availability of the wireless spectrum, how much money they have for upgrades, whether they can easily build or share more towers. In simple terms, operators have three options: add, optimise, and avoid. Resolving the "capacity gap" in order to maintain network quality is only one facet of the problem. The real "killer" issue is commercial: revenues are not rising in line with traffic. This creates what Telesperience terms "the revenue gap" [Tele10]. It adds to the challenges because operators are facing rising costs without receiving compensating revenue rises. This, in turn, constrains their ability to tackle the capacity crunch. To resolve this challenge, *operators need to find new revenue streams and optimise revenues from existing services*.

3 APPROACH

In a near future, finding new, alternative communication possibilities to help alleviate overloaded infrastructures will become a need in operated networks handling mobile data:

The MOTO project proposes to design, dimension, implement, and evaluate an architecture that takes advantage of the latest advances in opportunistic networking to achieve efficient *traffic offloading.*

Offloading strategies exploit the diversity of wireless access technologies to switch traffic from one access technology to another when deemed necessary. Indeed, in the 3G infrastructure, terminals are generally multi-homed, and many spots and areas are covered by several wireless broadband technologies (e.g., UMTS and Wi-Fi). Then, the cellular operators typically offloads traffic from the 3G network onto the Wi-Fi access points by automatic (or semi-automatic) connection of the users' terminals to known Wi-Fi access points. With the arrival of a truly converged Wi-Fi/LTE integrated infrastructure, more elaborate offloading strategies are under study and development. *The MOTO project explores a synergic use of a diverse set of complementary offloading techniques, by adding another layer of offloading through direct hop-by-hop communications between terminals.* This is illustrated in Figure 2. Such an approach is enabled by the fact that today mobile users' terminals are equipped with a range of wireless communication technologies, allowing them not only to easily and dynamically connect to different wireless infrastructures, even at the same time (e.g., cellular and Wi-Fi), but also to establish direct connections with each other while being connected to wireless infrastructures (e.g., establish ad hoc communications through Wi-Fi ad hoc or Bluetooth while being connected to a cellular network). Conceptually, MOTO will provide coordinated offloading through an agile, “overlay” control approach, consisting in offloading traffic across operators’ networks and on mobile networks without modifying the inner mechanisms of each technology.

MOTO’s objective is to leverage a customer-focused perspective and put the customer at the heart of their offloading and traffic shaping strategies, in order to ensure their success (revenue wise). In this respect, mobile and wireless telecommunications operators are developing new pricing strategies as an attempt to alleviate the revenue gap. The pricing model still commonly in use is to allow unlimited usage (turned in practice to a high volume cap, typically in the range of 5 Gbytes per month) combined with fair usage policy. Differentiating between users (especially the 20% heavy users who generate 80% of traffic load) is being increasingly explored as an alternative pricing model. MOTO’s offloading strategies match this approach and provide the operators with the flexibility to elaborate new tiered pricing parameters, which take into traffic classification (e.g., with respect to service type or delay tolerance) and user consumption.

The gain of opportunistic offloading comes from the existence of redundant traffic. Indeed, bandwidth shortage is going to be particularly severe when a very large number of users located in a relatively limited region wish to access popular content items. This is a relevant case for content access. Typically, content popularity follows Zipf-like distributions, i.e., a small subset of content items is extremely popular and is accessed by a very large number of users. In such scenarios, the same content item will be requested by a significant fraction of the users, and the total request in terms of bandwidth will peak (sort-of “Slashdot” scenarios). We focus on content types with looser constraints, with respect to audio/video live streaming, in terms of delivery schedule. We assume that, while it is important for the users to receive content items within a given deadline, it is not fundamental to receive a stream of data with a given rate throughout the whole transfer (in the extreme case, it is acceptable for the users to receive the content even in a single bulk, by the stated deadline). Note that all content types but live audio/video streaming satisfy these requirements.

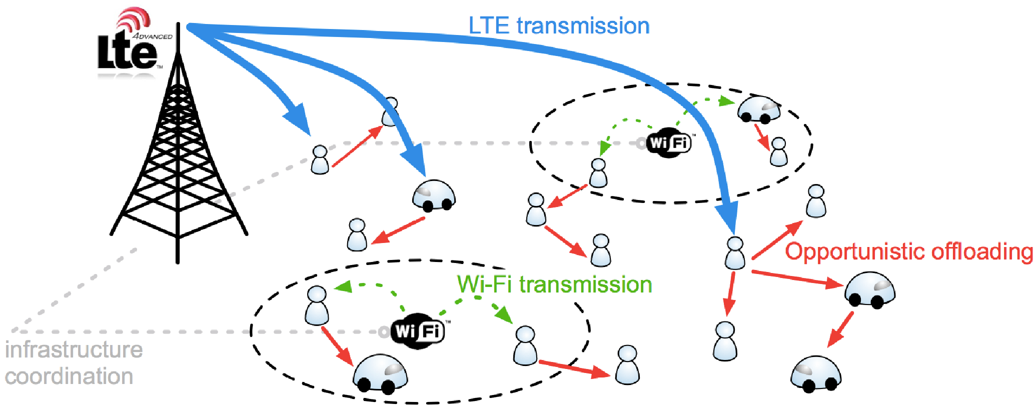


Figure 2. Illustration of offloading possibilities in MOTO.

Such scenarios can be only partially – if at all – addressed through 4G multicast techniques (such as the Evolved Multimedia Broadcast Multicast Service – EMBMS), which is, on the other hand, very well suited for audio/video live streaming. Unlike in streaming services, in the scenarios we consider the traffic from the content provider to the users is not synchronised, because users do not request the same content items at exactly the same time. However, content items need to be delivered with high reliability to each user, which is a difficult challenge for 4G multicast services: as we do not focus exclusively on the delivery of audio/video content, tolerance to partial delivery of content items is in general very low in our scenarios. With 4G/LTE techniques, such scenarios can be supported only by establishing direct connection between the users and the content provider. During peaks of demands this will not be viable, as the operator infrastructure cannot be dimensioned for peaks. What we propose is – conceptually – a *generalisation* of a multicast service, which is not supported by cellular technologies. Moreover, with respect to conventional multicast services, what we propose is lightweight, i.e., it requires lighter procedures for group management and state maintenance with respect to conventional multicast services.

4 GOALS

The MOTO project proposes to investigate the limits of 4G/LTE technologies in congested conditions and how opportunistic networking (an evolution of the Delay-Tolerant Networking (DTN) paradigm) can be used in a trustful manner to offload part of the traffic from the 4G/LTE network. Specifically, in the project view, the offloading operation on the opportunistic network formed by the users' devices will be synergic with the traffic management on the operator network and with offloading across different wireless infrastructures (such as 4G/LTE to Wi-Fi), and under the control of the operator.

While a user-terminal supported offloading process with intelligent control from the network operator would rise undisputable benefits from an unsynchronised content downloading quality of experience (QoE) perspective, specially under network congested conditions, these benefits should be balanced against a correct operation of the service security-wise. MOTO service operation is performed in a more open-network scenario, i.e., delegating the user terminal some networking and/or group management functions. Therefore, end-to-end operational security assurance mechanisms should be addressed in a multi-domain and dynamic environment.

The MOTO project proposes a traffic offloading architecture that exploits in a synergic way a diverse set of offloading schemes, including offloading from cellular to other wireless infrastructures (such as Wi-Fi), and also offloading to multi-hop ad hoc communications between users devices. In practice, this architecture is promised to offer many other advantages in addition to reducing load on operators' infrastructures:

- Reduce communication delays by pushing the information closer to users. Indeed, downloading data from geographically close neighbours can considerably reduce delays.
- Exploit "social" information to build, maintain, and adapt the constructed ad hoc networks. It is clear that users present at the same event in the same time-share at least one common interest.
- Reduce energy consumption by limiting redundant traffic on the infrastructure and by allowing communication among nearby peers (reduced transmission powers).

More specifically the MOTO project is structured around five scientific and technological objectives:

Objective 1 (*To design an integrated operator-managed offloading system*). The MOTO system design integrates offloading within the 3GPP (3G/4G) and wireless broadband Internet infrastructures and standards. This new design adds complementary functions for mobile terminal management, trust, flow and session management.

Objective 2 (*To design combined offloading algorithms*). Offloading takes advantage opportunistically both of AP connectivity and terminal-to-terminal communication opportunities. The algorithms will support heterogeneous classes of services, including time-constrained flows in unicast or multicast modes, to increase overall capacity of the system.

Objective 3 (*To characterise the capacity benefits of the system*). Theoretical studies will take into account mobility patterns, traffic features, and green savings constraints that are typical of the use cases identified in the project (home, smart city, vehicular).

Objective 4 (*To perform fine-grained large scale evaluation*). The MOTO project will contribute to the development of an open source offloading simulation library within the ns3 simulation environment; it will include both infrastructure components (LTE and Wi-Fi) and terminal-to-terminal protocols. This platform will be used to perform large-scale evaluation of the offloading algorithms in terms of coverage, number of radio nodes and traffic patterns.

Objective 5 (*To carry out integrated prototyping and trials*). Technical feasibility and user acceptance of the system will be evaluated in the project. Partners' test platforms covering 3G/4G and Wi-Fi infrastructures, complemented with smartphone offloading application modules will be used to implement the key mechanisms of the offloading solution (terminal management, trust maintenance, offloading control and architecture integration).

5 MOTO TECHNICAL VISION

The technical vision adopted in MOTO to support offloading in the scenarios above is presented through the high-level conceptual architecture in Figure 3.

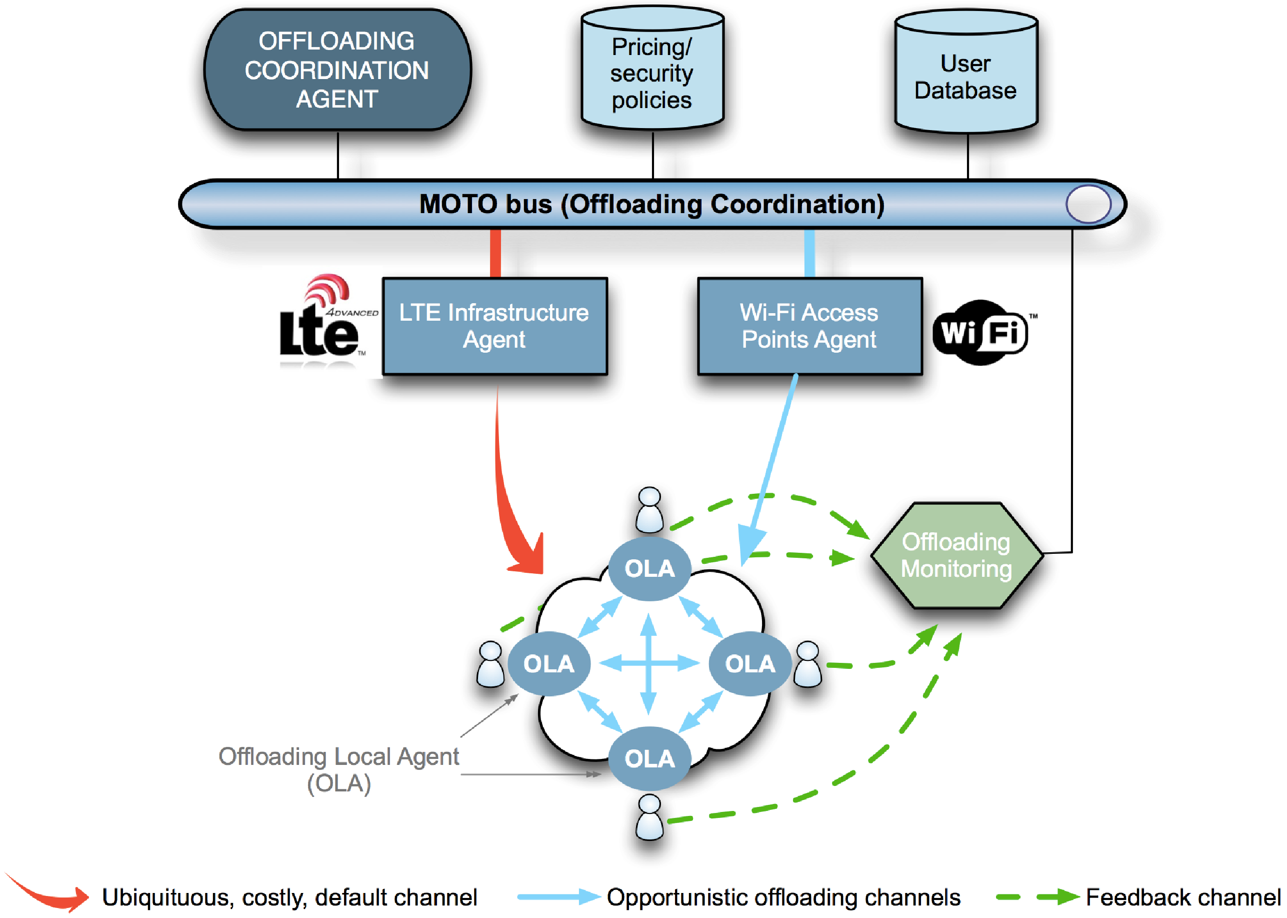


Figure 3. High-level MOTO architecture.

It is important to note, first of all, that the MOTO conceptual architecture nicely accommodates different forms of offloading that will be used in the project in a synergic way. This includes more "conventional" techniques, such as offloading traffic from a cellular network to a Wi-Fi network. Even in this case, note that MOTO will explore less conventional approaches, such as cases where the operator of the cellular and Wi-Fi networks are not the same, and where the Wi-Fi network is not even directly owned by the Wi-Fi operator (according to the FON paradigm). Moreover, the MOTO conceptual architecture supports more advanced forms of offloading, such as using terminal-to-terminal communications to offload traffic from any (cellular or Wi-Fi) wireless infrastructure, still under the control of the operator.

Terminal-to-terminal communications form what in the literature are known as opportunistic, delay-tolerant, challenged, or intermittently-connected networks[1] (the opportunistic and delay-tolerant concepts are hereafter used interchangeably) [Pel06, Zha06]. Opportunistic networks are a type of self-organizing ad hoc networks formed directly between mobile user terminals, by taking advantage of all direct connection opportunities between them (e.g., through Wi-Fi, Bluetooth technologies, and emerging standards such as Wi-Fi Direct). With respect to legacy ad hoc networks [CON07], in opportunistic networks a simultaneous

[1] Opportunistic, delay-tolerant, challenged, intermittently connected networks are used in the literature most of the time as synonyms, although sometimes they denote slightly different concepts. With respect to the MOTO solutions, they can be considered as synonyms.

multi-hop path between a source and a destination is not necessary to support end-to-end communications. Disconnections and network partitions are indeed totally tolerable in opportunistic networking. Messages addressed to a given destination are forwarded to "increasingly better" relay nodes (e.g., nodes that have a highest probability of meeting the destination in the near future), among the ones that can be reached at a specific time by the relay that is currently carrying the message. When no "better relays" can be identified, the message is kept at the current relay, until a better one "appears" in the network (e.g., because two nodes come into communication range because of the mobility of their users). Messages are thus progressively relayed towards the destination(s), by opportunistically exploiting contact events between nodes.

MOTO considers a broader class of opportunistic networks with respect to the typical paradigm. Specifically, in conventional opportunistic networks direct communication opportunities between terminals occur due to the mobility of the users, who come into contact once in a while and for a limited amount of time. MOTO will consider this type of opportunistic networks, as well as opportunistic networks where direct communication opportunities can arise also as a side effect of duty cycling of the ad hoc interfaces of mobile terminals. Due to energy saving reasons, because Wi-Fi and Bluetooth interfaces in ad hoc mode are typically energy hungry, operators and/or users may want to configure their mobile devices so that the ad hoc wireless interfaces are not continuously switched on, but dynamically alternate between active (energy consuming) and inactive (energy saving) states. Therefore, in a network even with only static nodes, whose wireless ad hoc interfaces are managed according to duty cycling schemes, devices cannot continuously communicate in ad hoc mode with each other (even if they are within each other communication range), but communication opportunities arise dynamically, when their ad hoc wireless interfaces happen to be active at the same type. MOTO thus considers both types of opportunistic networks, i.e., those formed because of real users' mobility and those formed because of duty cycling schemes.

Figure 3 captures the synergic use of all these forms of offloading, thus well illustrating the MOTO technical vision. In MOTO the data dissemination process, required in the identified scenarios, will only partly go through the "costly, default" channel, consisting of the LTE infrastructure (note that the term "costly" in the caption is used to denote that, if all users access content via this channel, the wireless infrastructure easily becomes congested, and this results in additional costs for the operator for overprovisioning it, which eventually result in additional costs also for the users). Part of the users will be reached by exploiting the availability of Wi-Fi access points, as well as by exploiting direct terminal-to-terminal communications, thanks to ad hoc opportunistic technologies. Orchestrating this process requires coordination between the various communication technologies, that is logically achieved through the "MOTO bus" and the "offloading coordinating agent", which implement the coordination and inter-technology scheduling policies investigated in the project. Therefore, MOTO will design an "overlay" layer on top of the various types of networks, which will work under the control of the operators, such that the offloading process can be dynamically monitored and adjusted, based on its own evolution, and on the dynamic conditions of the networks themselves.

The synergic use of different offloading technologies means that in MOTO a subset of the users will receive the content from one of the wireless infrastructures, and start propagating it epidemically through ad hoc opportunistic technologies that can be controlled by the operator on its customers' devices, as we sketch in the following. In this phase, opportunistic dissemination schemes may also exploit information about preference, behaviours, and mobility patterns of the users, stored in the "user database". With respect to conventional opportunistic data dissemination schemes, MOTO adopts a novel approach, whereby the wireless infrastructures will be used to implement a control loop on the status of the dissemination process. In fact, the wireless infrastructures will be used to monitor the status of the dissemination process (e.g., in terms of the fraction of users that have received contents by a certain time). The "offloading monitoring" part of the control loop provides necessary information to the offloading agent to supervise the possible re-injection of copies of the content via the infrastructure whenever it estimates that the ad hoc mode alone will fail to achieve full dissemination within some target delay. Note that, although there are certainly scalability issues that MOTO will address in the design of the control and terminal-to-terminal protocols, the load on the wireless infrastructures posed by such a control loop will be minimal, as it only requires mobile users to upload short control information (sort of ACKs) when they receive the content they are interested into.

Moreover, the availability of wireless infrastructures will be exploited to optimize the ad hoc opportunistic data dissemination process by providing contextual information that is typically not available in opportunistic networks. For example, cellular operators may predict very well (near) future cells and mobility patterns of their users, thus enabling MOTO to predict with some degree of accuracy – modulo the difference in communication ranges between cellular and Wi-Fi ad hoc technologies – which pairs of users will happen to be relatively close to each other and therefore could have terminal-to-terminal communication opportunities in the near future. Clearly, this information is one of the basis on which opportunistic data dissemination processes are built.

Last, but not least, the MOTO control loop is also used to monitor security issues, and guarantee that security profiles agreed upon between the operators and their customers are preserved also during the terminal-to-terminal dissemination process.

The significant innovation of its technical vision – and, in particular, the synergic use of different offloading mechanisms and the integrated use of wireless infrastructures and opportunistic ad hoc networks – allows MOTO to take the best features of both (infrastructure and ad hoc) wireless technologies. This is indeed a win-win situation, as the two technologies can nicely complement each other.

- The operator(s) can use the infrastructure(s) to directly provide content only to a subset of the mobile users, and offload the delivery to the remaining users to opportunistic networking techniques. This drastically reduces the load on the wireless infrastructure, by exploiting the capacity of terminal-to-terminal communications, which is most of the time unused.
- The opportunistic network will highly benefit from the presence of wireless infrastructures, as they are used as a lightweight signalling channel for the opportunistic network, in order to collect additional information on the topology of the opportunistic network and thus better control the dissemination process.

Thanks to this approach, the operator will decide how much bandwidth to allocate for supporting users in the identified scenarios in a flexible and efficient way, and will be able to handle peaks of traffic without overprovisioning the infrastructure and without blocking the service to its customers. The whole MOTO offloading process will be under its control. This is straightforward when the operator is the sole owner of the wireless infrastructures involved in the offloading process. When multiple operators co-operate in the offloading scenario (e.g., a cellular operator and a Wi-Fi operator such as FON), control is achieved by the fact that the MOTO inter-scheduling policies operate by taking into account Service Level Agreements between the operators. Finally, as far as the opportunistic dissemination process on mobile terminals, the simplest way is to exploit the customers of the operators only, and including functionalities in the operating systems of the mobile devices such that ad hoc communications are dynamically enabled through control messages sent by the operator. Clearly, such an approach is quite simple to implement, although suboptimal, as not all devices in the opportunistic network can be used. Solutions based on homomorphic functions also exist [Shi10], by which data can be disseminated by exploiting intermediate users that are neither aware of the content they disseminate, nor of the identity of the intended receivers.

6 METHODOLOGY

The overall innovation cycle of MOTO is illustrated in Figure 4 and consists of iterative cycles of design, evaluation, experimentation, and prototyping. Therefore, convergence towards the final project results will happen through continuous improvement, rather than via a pure waterfall method, since the proposed approach is known to be more robust, especially in complex projects carried out by independent partners, like MOTO. Evaluation includes approaches that are incrementally close to the prototyping activities, from analysis to simulation, and the emulation. This approach allows early, though approximate, feedback to be included in the design phase to detect major issues when they are easier to tackle, thus reducing risks.

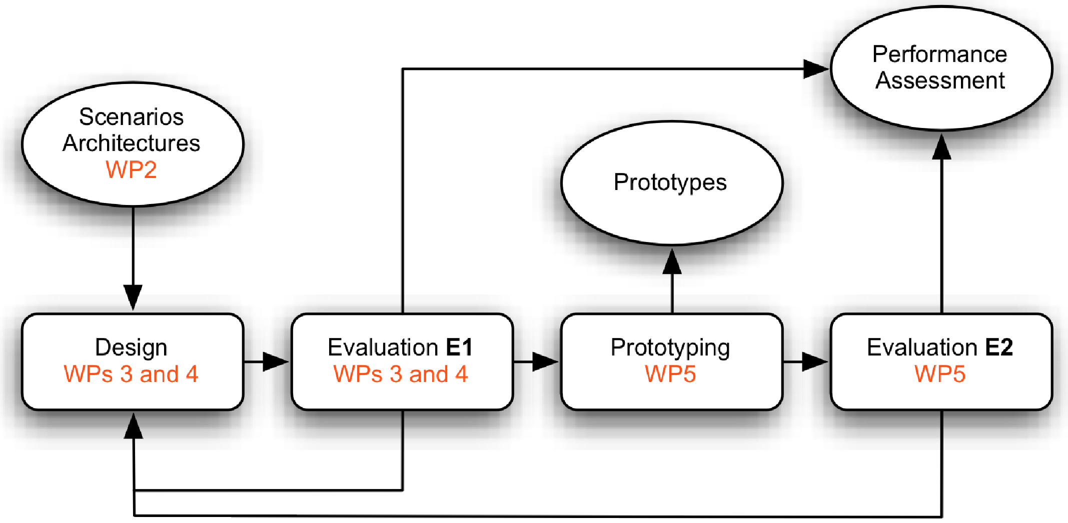


Figure 4. MOTO methodology.

The purpose of the design phase is to design the MOTO protocols and algorithms, taking as input the requirements derived from the MOTO reference scenarios and the MOTO architecture and the feedback received by the subsequent evaluation phases. In the evaluation phase E1 a thorough assessment of the performance and key properties of the algorithms and protocols is carried out, before generating real prototypes. Analysis and simulation techniques will be used for this evaluation phase, which are flexible and permit to characterize the behaviour of the algorithms and protocols relatively quickly. In the typical case, this phase will highlight design shortcomings, and therefore will prompt a revision of the design. The prototyping phase will be entered when algorithms and protocols perform satisfactorily, according to the evaluation results. Here real prototypes of the MOTO protocols and algorithms will be implemented and executed in the project testbed facilities. Eventually, joint use of simulation within the testbed facilities will be considered exploiting the emulation features of the tools, so as to test the systems under situations that cannot be reproduced, easily or at all, in real conditions.

The design phase is implemented by WP3 and WP4. Evaluation is realized on WP3, WP4 and the dedicated WP5. Specifically, WP3 and WP4 will mainly implement the evaluation phase E1, where the building blocks, protocols and algorithms are initially evaluated before prototyping. Phase E1 also corresponds to scenario-based simulation - carried out in WP5, where algorithms and protocols are evaluated in the specific reference scenarios of the project. Prototyping and the evaluation phase E2 will be carried out in WP5. Note that WP5 will also be responsible for providing the reference simulation and emulation platforms used in the evaluation phases.

7 CONCLUSION

The MOTO project gathers a team of experts in industry, university, R&D centres and operators. The complementary knowledge of the partners in 3GPP network architecture, 4G/LTE and Wi-Fi technologies, mobile terminal integration and application development, and trust and security will be combined to achieve the scientific and technological objectives of the project. With two operators and another two industry partners providing use cases, the business and technology target of the MOTO project is mainly to help alleviate traffic in the 4G/LTE infrastructure. The project will nevertheless propose a generic architecture, which is intended to be as general as possible (including situations involving other technologies).

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