TROPIC main achievements and exploitation prospects

The project aims at exploiting the convergence of pervasive small cells network infrastructure and cloud computing paradigms for virtualisation/distribution of applications and services that would otherwise run in the user terminal under a framework that optimises energy, communication and computation resources.

At A Glance: TROPIC

Distributed computing, storage, and radio resource allocation over cooperative smallcells

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Main Objectives

With the advent of more and more sophisticated applications for mobile users, high rate-demanding services and new habits of subscribers, wireless communications system designers are confronted to new challenges: providing ubiquitous availability, improving energy efficiency, enhancing system capacity and guaranteeing security. As some of these aspects cannot be simultaneously optimized in conventional systems, heterogeneous deployments based on mixed macro base stations and small cells (SCe) are expected to play a significant role in future wireless communications.

Small cells clouding merges cloud computing with small cells networking, thus enabling a capillary distribution of cloud computing capabilities closer to a huge number of mobile users

As a parallel track, cloud computing is becoming more and more important as a flexible, robust, highly-scalable and cost-effective tool to design, implement and deploy applications, allowing low-complexity terminals to have access to much larger resources than those available on typical user equipments.

While SCe networking and cloud computing are typically seen as two distinct fields, the main goal of TROPIC is to bring them within a common framework in order to provide an innovative tool able to provide enhanced experience to users both in terms of execution times and energy savings.

The innovative concepts proposed have been driven by university and research institutions, with the support of industry and telcos. The goal is to benefit operators (with a potential new stream of revenues), SCe manufacturers (with new products), application developers (more demanding applications can be designed) and end users (with enhanced experience). The project has focused on key questions that are at the centre of the system design:

- What are the communication and computational technologies required to exploit the convergence of pervasive SCe infrastructure and cloud computing paradigms for virtualisation/distribution of applications?
- What the advantage is in terms of spectral/energy efficiency and service effectiveness that can be achieved by the synergic femto-cloud approach?
- How the stakeholders can exploit the technology and benefit from the concept?

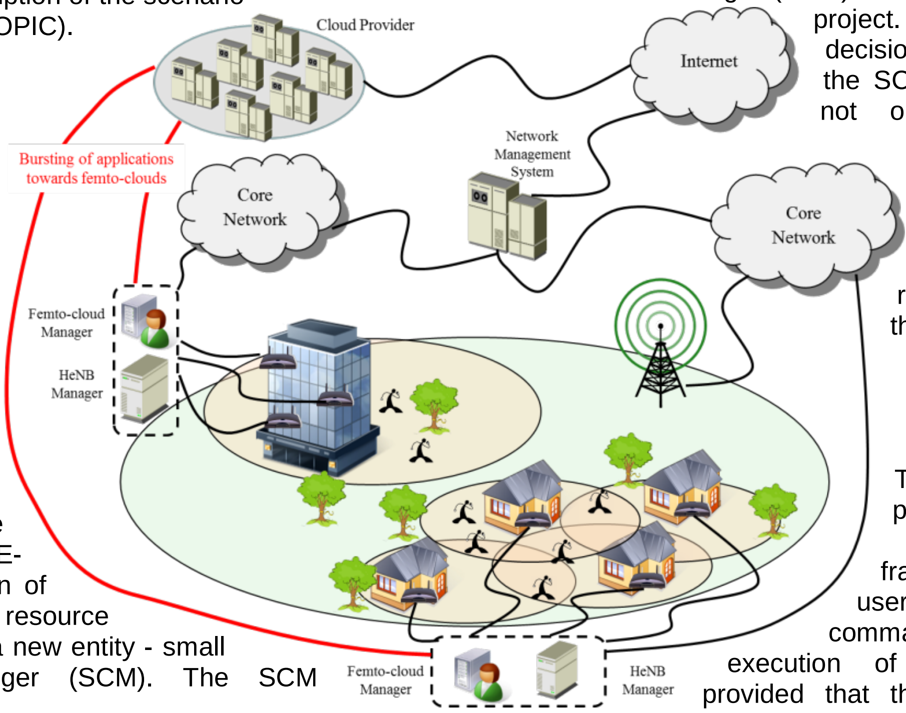
Challenges and Technical Approach

Two key observations establish the convergent innovation of TROPIC:

- pervasive small cells (SCe) deployments can be viewed as a networked, distributed infrastructure of devices, each equipped with some amount of computational power and storage;
- very demanding applications for mobile handsets (e.g. in terms of computation, storage, latency and power requirements) can be distributed and run over cooperating SCe of this networked infrastructure, by leveraging on the virtualisation and the distribution paradigms employed for cloud services.

The new paradigm proposed by TROPIC looks at the computation/communication/storage problem implicit in the development of many current applications for mobile terminals as a joint problem and, given the hardware and battery constraints, searches for the most effective solution in terms of computational capabilities and radio resource allocation.

TROPIC has designed a complete system that allows offloading computationally intensive applications from handheld devices to a cloud of new generation of small cells equipped with computing capabilities to be shared amongst a pool of users in order to deliver services with enhanced QoS, in terms of latency, service continuity, reduction of battery consumption, run applications that were just too heavy to execute on traditional mobile sytems, etc. (see figure below for a description of the scenario envisioned by TROPIC).



Key results

Architecture. TROPIC has defined a new architecture enabling offloading of applications to a cloud distributed over small cell base stations. The new architecture enhances the existing 3GPP LTE-A by incorporation of computing resource management by a new entity - small cell cloud manger (SCM). The SCM manages allocation of the computation resources in order to ensure efficient exploitation of both radio as well as computation resources and to minimize delay experienced by users and energy consumption of user equipment.

PHY layer. From a physical layer perspective, two objectives are relevant to the problem faced by TROPIC: i) enhancing spectral efficiency in dense small cells scenario; ii) providing PHY layer support to offloading techniques.

i) Several innovative contributions have been developed for enhancing spectral efficiency, including interference management through e-node B coordination, multipoint to multipoint (MP2MP) communications, collaborative sensing, traffic dependent PHY resource allocation. In particular, distributed network coordination mechanisms have been developed incorporating network-MIMO interference managemet and distributed scheduling. Inter-eNB. Over-The-Air (OTA) communication strategies and protocols have been proposed as well as distributed repair coding mechanisms.

ii) Being the PHY-layer support fundamental for computation offloading, TROPIC has derived energy consumption models for mobile terminals, instrumental for the development of energy efficient offloading mechanisms, with a special emphasis to the optimal energy/latency/complexity tradeoff.

Radio/computation resource management. The strategy to optimise the resource management while keeping the best possible quality of experience is carried out by a new entity called the Small Cell Manager (SCM) introduced by the project. The decisions taken by the SCM are based not only on the computational situation of the small cell cloud but also the radio context thanks to a specially designed monitoring system. TROPIC also provides an offloading framework for user terminals to command remote execution of applications provided that the small cell cloud will be able to deliver the service timely as expected by the user. In terms of KPIs, TROPIC contributes to a “Secure, reliable and dependable Internet with a "zero perceived" downtime for services provision” by approaching as much as possible resources to the end user.

Testbed. The simulator developed as demonstrator of the project combines models for the simulation of the processing on a virtualized environment with the models for the simulation of the LTE radio communications, inside the ns-3 framework. This platform, enriched with the new models, allows the analysis and the assessment of the performance of cloud computing over a new type of Small Cells with enhanced capabilities.

Standardisation and innovation. TROPIC activities resulted in a large number of contributions to 3GPP-LTE, among them, the most relevant (more can be found in http://is.gd/hZrK94):

- TR 36.932, “Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN”
- TR 36.874, “Coordinated multi-point operation for LTE with non-ideal backhaul”
- TR 36.300, “E-UTRA; E-UTRAN; Overall description; Stage 2”
- TR 36.423, “E-UTRAN; X2 Application Protocol”

Moreover, 11 patent applications have been submitted at the time of writing. A full list of patents developed within TROPIC may be provided under demand.

Exploitation prospects

TROPIC approach opens area for new use cases and a myriad of applications to be offered to application developers and end users. The SCM, small cell modules dedicated to computation and information exchange with the rest of the small cell cloud elements as well as the monitoring system can be exploited to implement a number of existing services and applications (e.g. location-based advertisement, gaming, etc.) moving the intelligence from remote clouds or the terminal itself to the network. New revolutionary applications can be designed in the future with TROPIC in mind and run on mobiles---applications that have tight real-time requirements or high computational load and that traditionally were out-of-reach for mobile systems. A prospect term contemplated is 2-4 years, depending on the adoption of the technology.

In the short term, the standardization achievements will be exploited by the entire LTE community in products and deployments. Finally, operators can obtain a new stream of revenues in terms of new services offered by adopting deployments of SCe based on TROPIC principles.

How the 5G programme can build on the results of the project

TROPIC is a cross-strand project and can be used as basis for a cross-strand proposal while including new targets. While the existing KPI are rather related to the PHY layer and do not reflect well the cross-strand targets. In this respect, TROPIC contributions focus also on enablers that will may have an impact on the development of new applications for the society progress.

TROPIC improvements allow up to 2.7x higher spectral efficiency at cell edge, 3x improved power consumption (offloading +PHY enablers) and 2…10x higher data rates (PHY enablers + 5GHz unlicensed). More precisely:

PHY layer. TROPIC activities in PHY address one of the main scenarios in 5G, namely very dense deployment through efficient and distributed interference management techniques. Furthermore, it provides the physical layer support for the design of a truly ubiquitous and pervasive system, with a special emphasis on latency control. This will lead to a fast deployment of SCes by the users and an increase of the amount of wireless links available also for other applications and devices.

System architecture. TROPIC inspire further use cases in which the virtual machines are not only dedicated to a pool of end users, but used by communication service providers in order to improve network management, by virtualising certain functions such as monitoring. See figure in the last page for the proposed system architecture and interfaces that include the small cell manager (SCM) within LTE.

Advanced services and applications. The methods and architecture proposed by TROPIC allow offloading and exploitation of additional computing resources of small cells enables easy and fast deployment of new real-time services and applications requiring heavy computation and low end-to-end delay. Furthermore, energy consumption at the user equipment can be significantly reduced. Availability of new services and improvement of user's experience by cloud-enhanced small cells should motivate users to deploy their own small cells (SCes).

Testbed. The models developed for ns-3 can be used as simulation base for proving future new algorithms, communication techniques or further developments in the architecture. The ns-3 platform adopted is widely used in the research community and the model of the virtualized platform, the resources management or the interference mitigation can be used not only over the LTE architecture, thanks to the modularity.

Priorities for the next work programme (2016-2017) in relation to 5G

A key priority is to define efficient pervasive systems that entail a joint allocation of radio and computational resources throughout the network, incorporating energy efficiency and latency control mechanisms. This involves the definition of cross-layer approaches involving from physical to application layers. This should be a central topic for a research action and under an innovation umbrella.

A second priority should be on cross-strand proposals addressing new professional/industrial applications with impact on 3GPP architecture and spectrum usage; the spectrum and ubiquitous access shall use all the existing spectrum holes, especially those at lower frequencies, licensed or unlicensed, and including a combination of transmission mediums for ubiquitous access.

References

Most of project results gave rise to a large number of publications in the most prestigious journals and conferences. These are selected ones (more in http://is.gd/9o2NWf):

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