SECRET - Secure Network Coding for Reduced Energy Next Generation Mobile Small cells

A European Training Network in Wireless Communications and Networking for 5G

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***Abstract*— SECRET is a collaborative European Training Network (ETN) committed to create an "excellent" educational training platform for Early Stage Researchers (ESRs) in the field of wireless communications and networking for 5G. The project is recently funded by the European Commission under the H2020 research and innovation program, through the Marie Curie People Program.**

This proposal targets to narrow the gap between current networking technologies and the foreseen requirements of future 2020 networking, through the recruitment and training of 17 ESRs. SECRET aims to strike a note by delivering higher capacity, ability to support more users, and lowering the cost per bit by adopting technology trends widely accepted to form part of the 5G roadmap, through the deployment of new disruptive "femtocell" type cells on demand, to what we refer to as mobile small cells. This will be complemented by a wireless high-speed fronthaul to bridge the small cell network to the core. Moreover, novel techniques will be investigated, including "network coding", "cooperation", and "energy-aware smart front-end". Additionally, due to the confidential information that will be communicated over in future networks, a lightweight security framework built on secure network coding will be proposed.

Keywords—Horizon 2020; Marie Curie Actions; Small Cells; 5G; Network Coding; Antennas; Power Amplifiers; Security;

I. INTRODUCTION

The foreseen increase in the number of connected mobile devices coupled with the ever more stringent QoS requirements from emerging broadband services, means that employing today's 4G wireless technologies and strategies for network expansion will fail to deliver competitive user tariffs as the transmission cost per bit is set to rocket. Buying more spectrum or infrastructure to accommodate extra users will no longer solve the issue of operators meeting customer demand. As the 4G chapter closes, new disruptive networking paradigms are needed to secure the 5G market and foster growth for the future. Certain technology trends, properties and offered services have been widely accepted to form part of the highly anticipated 5G [1], [2]. 5G stakeholders are unanimous that densification of mobile networks is the way forward for 5G, catering for providing hot spot islands of very high speed data. A step towards this vision is currently in place in legacy 4G networks by the adoption of multi-tier heterogeneous network, including macro, pico and metro-cells, C-RAN services to provide coordinated scheduling exploiting the notion of remote radio units (RRUs), and device-to-device communications for traffic offloading and proximity based services [2]. Additionally, cooperation and network virtualization are expected to play main roles in 5G systems [2]. However, the technology roadmap for 5G will persevere with small cells, as the most effective deployment for delivering ubiquitous 5G services in a cost-effective and energy-efficient manner.

In this context, SECRET targets to design, implement and showcase a new networking topology that delivers ubiquitous mobile small cell access to support future emerging broadband services. This proposal aims to narrow the gap between current networking technologies and the foreseen requirements of future 2020 networking and beyond, providing higher network capacity, ability to support more users, lower cost per bit, better energy efficiency, and finally provide a flexible multiple access architecture to support the foreseen services and devices (Internet of Things (IoT), e-Health, and mission critical services [3], among others).

This paper presents an overview of the ITN-SECRET project [4], highlighting the motivation behind it, along with its vision, objectives, and research methodologies. The paper also introduces the innovative training program of the project.

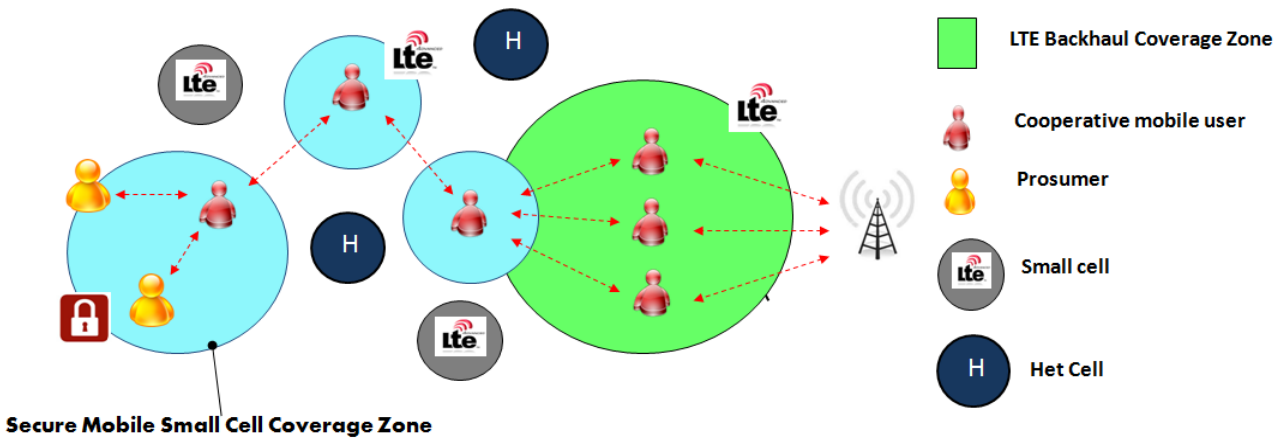

Fig. 1. Mobile small cells scenario

II. SECRET Vision and Objectives

A. Overall vision

The SECRET project builds on technology trends, widely accepted to form part of 5G, by providing a virtual cooperative wireless networks of small cells. The project plans to go beyond the current vision of small cell densification of 5G by proposing a disruptive new "femto-cell" like paradigms where end-users play the role of prosumers of wireless connectivity, which is referred to as "Mobile Small Cells". Another dimension of innovation of SECRET training program is the provision of wireless front-haul to provide high-speed reduced-cost energy-efficient connectivity to mobile small cells.

To this end, SECRET aims at researching ubiquitous mobile small cell access based on exploiting disruptive technologies such as "network coding" and "cooperation" in synergy with a "security framework" and "energy-aware smart front-end". These small cell hotspots will form a wireless-network-of-mobile small cells, so that prosumers at the cell edge, or in low coverage area can have access to high speed networking. The envisioned scenario is shown in Fig. 1. This opens up new research challenges in terms of investigating new networking topologies, architectures, and transceivers that can provide a "stable connection" during the session, and attain the desired trade-off between energy saving, and cell throughput capability, whilst still maintaining QoS. The mobile small cells will be set-up against a backdrop of HetNets, where we consider other small cells (such as femto, or pico) and heterogeneous cells that include WiFi hotspots, among others. The dense deployment of these cells, and their coexistence are all new research challenges to be considered in SECRET.

The SECRET project will help current mobile standards to move from the classical non-cooperative paradigm towards a more cooperative approach which is more user-network centric, where the resources of all devices are seen as a "pool of resources" to be used by the network as a vehicle for effective use of the mobile network leading towards enhanced spectral and energy efficiency. Indeed, SECRET represents a unique opportunity to break the femto-barrier and the potential to reduce the energy consumption in the network by a factor of 10, while providing higher data rates, higher capacity and ubiquitous service through reduced-cost solutions.

It is worth mentioning here that the main objective of the SECRET Network is the training of early stage researchers (ESRs); hence, all efforts and allocated budgets will be dedicated towards this goal. To train ESRs and prepare them ready for a career in the field of the next generation of mobile communications (specifically 5G), those researchers need a solid understanding of multidisciplinary research fields, covering protocol design, optimization algorithms, cross-layer design, etc, at the different layers of the protocol stack. We believe that it is hard for any advanced academic courses to cover all those topics; hence ITN-SECRET is planned to provide ESRs with training in all those fields, along with some courses to cover soft and communication skills.

B. Research Objectives

In more details, the SECRET project will train the 13 ESRs, through targeting certain technical research objectives:

1) New radio architectures based on mobile small cells targeting reduced-cost, high-speed and energy-efficient connectivity on demand: SECRET envisages a series of mobile small cells covering the urban landscape, which are virtual in nature since they can be set up on demand at any place, and at any time on any device which are coordinated by SECRET enabled mobile handsets. These mobil small cell hotspots, from the end-user perspective, are the vehicle for experiencing a plethora of 5G broadband services at low cost with reduced impact on mobile battery lifetime.

2) Network Coded Cooperation for mobile small cells to ensure high error resiliency and efficient spectrum usage: In this emerging heterogeneous networking environment, two communications technologies are playing a prominent role: cooperation, and small cells. The interplay between these can provide an architecture for the mobile cell concept, and provide a footing for the energy and throughput gain required for 5G networks and services. Therefore, a key objective is to address the interplay between network coding and cooperation

adopting an interdisciplinary design approach towards Network Coded Cooperative (NCC) networks to harness the complementary merits of both technologies, whilst overcoming their main limitations.

3) Secure networking coding for mobile small cells: Security has become an important issue that needs to be addressed in an era where cybercrime is an occurring theme in our internet highways. These types of events are foreseen in SECRET scenarios, since confidential information will be communicated via the mobile small cell network, and relayed over the high speed network-coded cooperative connectivity using foreign relaying nodes. Therefore, a framework including secure network coding solutions will be addressed;

4) Energy efficient and multi-standard RF front-end for next generation multihoming: Next generation handsets will need to be green or in other words "energy aware", so as to support future emerging smart services that are likely to be bandwidth hungry, as well as support multi-mode operation (5G, LTE, LTE-A, HSDPA, 3G among others) in HetNet environments. SECRET will address the RF front end and propose a multi-standard flexible transceivers considering power consumption as a key design metric. This will include investigating RF building blocks such as energy efficient power amplifiers (PAs) and antenna techniques, and tuneable RF bandpass filter design;

5) Enabling mobile Small Cells and Network virtualization: We finally aim to provide a small cell test-bed implementation emulating a 5G system, and will act as a vehicle for promoting collaborative ESR research projects, since key algorithms can be tested and optimised here.

C. Partners

We understand that the success of any collaborative project heavily relies on the correct choice of partners; hence the partners of ITN-SECRET were carefully chosen to satisfy all the required expertise in a multidisciplinary consortium. The SECRET project will benefit from the productive collaboration of 8 European partners, in 5 different countries, including 3 universities, 1 research center, 2 companies, and 2 small/medium enterprises (SMEs). The partners of the ITN-SECRET are:

1) Instituto de Telecomunicações, Aveiro, Portugal
2) Technische Universitat Dresden, Dresden, Germany
3) University of Bradford, Bradford, United Kingdom
4) University of Patras, Greece,
5) Huawei Technologies, Finland
6) Acticom GmbH, Berlin, Germany
7) SARAS Technology Limited, Leeds, United Kingdom
8) PROEF GPS, Porto, Portugal

The successful collaboration of the partners is guaranteed harnessing on previous collaboration between partners in previous EU collaborative projects, and the experience of the coordinators in participating in a successfully led ETN, such as ITN-GREENET [5].

III. Research Methodology and Innovation

A. Technical approach

The training program constitutes of seven WPs: a WP devoted to management (WP1), a WP dedicated to training (WP6), a WP devoted to dissemination (WP7) and four technical WPs (WP2–WP5). In a nutshell, the technical WPs are designed so as to implement the full project objectives in terms of training, and provide as a tangible output a demonstrator that validates the proof-of-concept of using mobile small cells for 5G services. The methodology adopted in each technical WP is given as follows:

1) WP2: Network-Coded Cooperation for Mobile Small Cells and Coexistence: WP2 foresees the analysis, design and optimization of network coded cooperative (NCC) networks to deliver disruptive radio networking topologies to emulate mobile small cells to provide femtocell-like services on the move. To promote the take-up of this technology, WP2 also examines how these cells can coexist in a HetNet environment which is deemed pivotal to the evolution of 5G; these small cells are not only LTE based, but is technology agnostic to adopt 5G technology once standardised and additionally could encompass WiFi hotpots among others.

Innovation: To support reliability, throughput, coverage, and coexistence requirements of 5G wireless systems in a cost-effective and energy-efficient manner, SECRET will investigate three fundamental issues:

- Analysis, design, and optimization of NCC communications for mobile small cells. In SOTA [6], [7], it is shown that the most challenging design problem of NCC communications is to develop relaying protocols and network codes that can guarantee good end-to-end performance without sacrificing the throughput; however the fundamental trade-off is still unknown. In literature, only a single relay is considered [7] or only binary modulations are considered [6]. In SECRET, we go beyond these preliminary works with the aim of analysing the performance and proposing new solutions for arbitrary network topologies and transmissions technologies. Major advance will be the analysis of random relay deployments, which has never been addressed before.
- Analysis, design, and optimization of small cell overlay deployment for HetNets. In literature [8],[9], it is shown that performance and design of small cell overlay networks depend critically on the spatial configurations of the small cells, and that new methodologies and metrics must be introduced for the optimization of such systems. In SECRET, we propose to leverage the application of Stochastic Geometry [10] to design these networks in a practical and cost-effective way. In particular, we will analytically study error performance, throughput, and coverage of small cell-overlaid 5G systems, and will propose new transceiver designs, cell association mechanisms and mobility approaches for better coverage, reliability, seamless handover and service continuity.
- Finally, to realize the challenging expectations of 5G systems, we will study and design NCC communications protocols that can coexist and contend with macro-cells,

femto-cells and small cells for improving reliability, rate, coverage, and for a better utilization of available resources, i.e. spectrum/energy. The analysis of relay networks in the presence of femto-cells interference has been very recently considered [11], [12]. However, a single relay with known fixed location was considered and no network coding was investigated. In SECRET, we will consider general network topologies (with random relay locations) and transmission technologies. This research problem has never been tackled.

2) WP3: Secure Network Coding for Trustworthy Mobile Small Cells: WP3 studies network coding security of next generation small cells, incorporating a "Network Coding overlay". Given that we employ network coding to form new energy efficient and high speed networking topologies for mobile small cells, security attacks, such as pollution attacks and Denial of Service (DoS) attacks, resulting in severe network performance degradation and energy waste should be addressed effectively and efficiently. Towards this direction, this WP targets the design and implementation of efficient secure network coding mechanisms and schemes to mitigate such attacks in the envisioned network-coding enabled mobile small cell network. Specifically, we plan to provide a secure network coding framework including i) new integrity schemes against pollution attacks, ii) secure key management schemes for the new integrity schemes, and iii) a collaborative intrusion detection and prevention mechanism to mitigate DoS and Distributed DoS (DDoS) attacks.

Innovation: In order to achieve secure network coding for next generation cooperative mobile small cells, SECRET extends previously proposed mechanisms by:

- Oliveira et. al. [13] proposed a set of secure protocols that rely on simple network coding operations to provide a robust and low complexity solution for sharing secret keys among sensor nodes, including pairwise keys, cluster keys, key revocation and mobile node authentication. Despite the interesting achievements, the use of network coding was limited to XOR operations. We aim to extend this work by exploiting random linear network coding as well as modifying and adapting the proposed protocols to multi-hop secret key distribution in highly dynamic wireless networks.
- Lima et al. [14] exploited the algebraic characteristics of random linear network coding to protect wireless video streaming from eavesdropping for the cases, where only some of the users are entitled to receive the highest quality. The achieved results proved the concept of differentiated levels of security for distinct users and the resilient nature of network coding to packet losses. Nevertheless, the presented solution is still vulnerable to pollution attacks. In order to achieve a resilient network coding in the presence of such attacks, we propose efficient integrity schemes that validate each received packet at a node (achieving a one-hop containment). Taking into consideration that in network coding systems standard digital signature schemes do not apply, we propose to solve this problem by exploring and comparing two approaches using: (i) homomorphic MAC [15]; (ii) homomorphic signatures [16].

3) WP4: Green RF for 5G Handsets: WP4 addresses energy efficient multi-mode RF front-end for next generation handsets. The key tasks will encompass techniques and implementation of functional entities, so as to minimize the carbon footprint in mobile handsets. The work will address the RF front end in handset devices and investigate multi-standard flexible transceivers (RF and baseband) considering power consumption as a key metric. Moreover, this includes strategies for optimizing the RF front end / antenna matching for higher energy efficiency, efficient PAs and antenna techniques to improve energy efficiency with limited complexity.

Innovation: It is apparent that the reliance on a single technology will no longer form part of the mobile communication paradigm, and will require very careful integration of diverse radio technologies in a cost-effective way. Therefore in SECRET we propose to:

- Extend the current Doherty amplifier implementation [17] towards a three step approach to promote efficiency enhancements and linearity compensation in PA design.
- Design a new reconfigurable switchable filter using Varactor technology with emphasis on lowloss, low-power consumption, reduced size and high-Q, which would also allow an easy integration with the CMOS PA.
- Address the limitations of both printed monopole and planar inverted-F antennae (reduced bandwidth and sub-optimal pattern shaping) by enhancing both efficiency and impedance bandwidth using the tuneable antenna concept without increasing the antenna size. Active devices (varactor switches) will be explored to achieve this goal to operate in several different modes.

4) WP5: Enabling Mobile Small Cells and network virtualization: WP5 addresses the proof-of-concept for mobile small cell technology, which includes not only a feasibility study, but is complemented by a concrete study on how small cell technology could be the springboard for network sharing in the form of network virtualization. This WP will build a small cell test-bed supporting different types of data with emphasis on real-time video which is the most demanding dominating use-case in 5G [18], and will act as a vehicle for promoting collaborative ESR research projects, since key algorithms in WP2-3 can be tested and optimised here.

Innovation: We go beyond the SoTA through two main approaches:

- Design and implement a novel architecture to deliver femtocell like services based on mobile small cell philosophy. The new topology targets four degrees of freedom: i) mobile devices are able to connect to each other forming a cooperative cluster, which supports multi hop connections and not just single hops as in existing approaches; ii) at least one but potentially multiple devices in the meshed, cooperative cluster will connect to the overlay network to grant IP access to the entire cooperative cluster. Therefore multi path routing is needed to exploit the multiple

cluster heads. Clearly, the selection of those cluster head(s) is a possible optimization problem that does not exist in the SOTA; iii) network coding is used at each node as well as in the overlay network to be able to efficiently support the inherently multihop nature of the cooperative cluster as well as to support seamless connectivity between multiple cluster heads and the overlay network; iv) each of the nodes is willingly participating in the cooperative cluster (no forced cooperation and no altruism) and incentives are required, i.e. each participating device, including cluster heads, should have a tangible gain from participating in the cluster.

- Small cell virtualization for efficient network sharing: research in architectural solutions and algorithms required to address the emerging virtualized small cell multi-tenancy requirements. The requirements defined by the 3GPP SA1 RSE study item will be considered and extended focusing on the design and evaluation of solutions aimed at minimizing operators OPEX and CAPEX while maximizing multi-tenancy revenue. These works will include mobile small cells, within a HetNet environment.

B. *Training Program*

SECRET is committed to recruit 13 ESRs for a time period of 36 months each. ESRs will be recruited through a competitive process, and each will be supervised by more than one partner of the consortium. The recruiting process will consider a gender balance. Each ESR will develop a personal research program within the premises of the hosting partner, and will spend a 6 month secondment period at the premises of another partner in the consortium under local supervision. The training program will include:

1) Traditional training by means of Ph.D. courses, tutorials, seminars, workshops, and international conferences.
2) Training through research, which foresees the involvement of the ESRs within different research projects at the hosting partners, as well as the development of his/her individual research program.
3) Complementary training, which foresees the attendance of specific courses aiming at improving soft skills, such as presentation, paper writing, patent writing, etc., in addition to business development and enterpreunership.

IV. Conclusion

In this paper, we have described SECRET, a recently–funded European project through H2020 Marie Currie People Program. The project aims at designing next generation energy-efficient wireless networks. SECRET foresees the collaboration of 8 European partners equally distributed among academia, and industry, which will synergically work to provide advanced training to 13 ESRs recruited by the consortium. The SECRET project targets to deliver higher networking capacity, ability to support more users, lower cost per bit, enhanced energy efficiency, and finally engineered to provide seamless connectivity to many of the new services and devices that are foreseen in 5G, that include mobile broadband connectivity, IoT and mission critical services.

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References

[1] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, et. al, “What will 5G Be?”, *IEEE J. on Selected Areas in Comm.*, vol. 32, no. 6, pp. 1065-1082, June 2014

[2] E. Hossain, and M. Hasan, “5G Cellular: Key Enabling Technologies and Research Challenges”, *IEEE Instrumentation and Measurement Magazine*, vol. 18, no. 3 pp. 11-21, June 2015.

[3] M. F. Domingues, and A. Radwan, “Optical Fiber Sensors for IoT and Smart Devices”, *Springer*, SpringerBriefs in Electrical and Computer Engineering, ISBN 978-3-319-47349-9.

[4] ITN-SECRET Project at http://h2020-secret.eu/

[5] M. Di Renzo, L. Alonso, F. Fitzek, A. Foglar, F. Granelli, F. Graziosi, C. Gruet, H. Haas, G. Kormentzas, A. I. Perez, J. Rodriguez, J. Thompson, and C. Verikoukis, “GREENET – An Early Stage Training Network in Enabling Technologies for Green Radio”, *VTC Spring 2011*, Budapest, Hungary, May 2011.

[6] M. Di Renzo, M. Iezzi, and F. Graziosi, “On Diversity Order and Coding Gain of Multisource Multirelay Cooperative Wireless Networks with Binary Network Coding”, *IEEE Trans. Vehicular Technology*, vol. 62, no. 3, pp. 1138-1157, 2013.

[7] W. Guan, and K. J. Ray Liu, "Mitigating Error Propagation for Wireless Network Coding", *IEEE Trans. Wireless Comm.*, vol. 11, no. 10, pp. 3632- 3643, 2012.

[8] C. Merola, et. al, “Average symbol error probability in the presence of network interference and noise”, in proc. IEEE ICC, pp. 2585–2590, June 2012.

[9] M. Di Renzo, et. al, “Simplified expression of the average rate of cellular networks using stochastic geometry”, in proc. *IEEE ICC*, pp.2398–2403, June 2012.

[10] M. Haenggi, et. al, “Stochastic Geometry and Random Graphs for the Analysis and Design of Wireless Networks”, IEEE JSAC, vol. 27, pp. 1029–1046, 2009.

[11] A. Chopra, “Modeling and mitigation of interference in wireless receivers with multiple antennas”, Ph.D. Thesis, The University of Texas, 2011.

[12] F. B. Saghezchi, A. Radwan, J. Rodriguez, and T. Daguiklas, “Coalition Formation Game toward Green Mobile Terminals in Heterogeneous Wireless Networks,” *IEEE Wireless Communications*, vol. 20, no. 5, pp. 85-91, Oct. 2011.

[13] P.Oliveira ,J. Barros, “A Network Coding Approach to Secret Key Distribution”, IEEE Trans. Inform. Forensics and Security, vol.3, no.3, pp. 414-423, 2008.

[14] L. Lima, et. al, “Secure network coding for multi-resolution wireless video streaming”, IEEE J. Sel. Areas Comm., vol. 28, no. 3, pp. 377-388, 2010.

[15] Z. Yu, Y. Wei, B. Ramkumar, Y. Guan, “An Efficient Signature-based Scheme for Securing Network Coding against Pollution Attacks”, In proc. IEEE INFOCOM, pp. 2083-2091, 2008.

[16] L. Lima, et. al “ On Counteracting Byzantine Attacks in Network Coded Peer-to-Peer Networks”, IEEE JSAC, vol. 28, no. 5, pp. 692-702, June 2010.

[17] A.S. Hussaini, et. al, “Efficient Multi-stage Load Modulation Radio Frequency Power Amplifier for Green Radio Frequency Front End,” IET Science, Measurements and Technology, vol. 6, no. 3, pp.117–124, May 2012.

Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017, available at http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html