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Showcase Paper

Cognitive radio and cooperative strategies for power saving in multi-standard wireless devices

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Abstract: Energy is a critical resource in the design of wireless networks since wireless devices are usually powered by batteries. Without any new approaches for energy saving, 4G mobile users will relentlessly be searching for power outlets rather than network access, and becoming once again bound to a single location. To avoid the so called 4G "energy trap" and to help wireless devices become more environment friendly, there is a clear need for disruptive strategies to address all aspects of power efficiency from the user devices through to the core infrastructure of the network and how these devices and equipment interact with each other. The ICT-C2POWER project is the vehicle that will address these issues through cognitive techniques and cooperation. The C2POWER case study is to research, develop and demonstrate energy saving technologies for multi-standard wireless mobile devices, exploiting the combination of cognitive radio and cooperative strategies, while still enabling the required performance in terms of data rate and QoS to support active applications.

Keywords: Energy Saving, cognitive radio, Cooperation, Vertical Handover, Short-range Communications, Energy trap

1. Introduction

The promise of a truly mobile experience is to have the freedom to roam around anywhere and not be bound to a single location, however, the energy required to keep mobile devices connected to the network over extended periods of time quickly dissipates. In fact, energy is a critical resource in the design of wireless networks since wireless devices are usually powered by batteries. Battery life time has been identified by TNS report [1] as the number one criteria of the majority of the consumers purchasing a mobile device. Reaffirming this, concern with using up battery is one of the top reasons why consumers do not use advanced multimedia services on their mobile more frequently.

Battery capacity is finite and the progress of battery technology is very slow, with capacity expected to make little improvement in the near future. In [2] it is claimed that battery capacity has only increased by 80% within the last ten years, while the processor performance doubles every 18 months following Moore's law. In terms of power consumption we have moved from a relatively low 1-2 W range in the first generations to around twice in 3G mobile devices. The perspective for the future does not look encouraging in this aspect, as one could easily expect another doubling in the power demand for 4G devices.

4G devices are expected to support higher data rates and multi standard radio interfaces (UMTS, LTE, WiFi, DVB-H, Bluetooth, etc) to provide users with a continuous connection. However, state-of-the-art multi standard devices have high power requirements for maintaining two or more radio interfaces, in addition, advanced imaging features (camera, high-definition display, etc.) and GPS/Galileo receivers will increase considerably the power demand of 4G handsets. In [3] it is envisaged that a dramatic increase in energy consumption of 4G mobile device will make active cooling a necessity. Even though active cooling is not an attractive solution for users and manufactures, some researchers have recently started studying the performance of fans within mobile phone architectures [4]. This is in fact becoming a key concern: there exists a continuously growing gap between the energy consumption of emerging radio systems and what can be achieved by battery technology evolution, scaling and circuit design progress, system level architecture progress, and thermal and cooling techniques.

Therefore, one of the biggest impediments of future wireless communications systems is the need to limit the energy consumption of the battery-driven devices so as to prolong the operational times and to avoid active cooling. In fact, without new approaches for energy saving, there is a significant threat that the 4G mobile users will be searching for power outlets rather than network access, and becoming once again bound to a single location. Some authors describe this effect as the "energy trap" of 4G system [5].

However, despite recent efforts, current state-of-the-art energy saving technologies cannot avoid the envisaged "energy trap" of 4G handset devices. Hence, there is a clear need for new disruptive strategies to address all aspects of power efficiency from the user devices through to the core infrastructure of the network and how these devices and equipment interact with each other. Cognitive radio and cooperative networks are becoming key disruptive technologies in the field of wireless communications. Cognitive radio has been used mainly to improve spectrum efficiency and the majority of cooperative concepts have been developed with the goal of enhancing the individual and/or group wireless link capacity.

The ICT-C2POWER project will go beyond the state-of-the-art, by investigating how these new paradigms (cognition and cooperation) can be also applied for reducing power consumption of wireless mobile devices. This paper presents the scope of this visionary project where section 2 provides the objectives; section 3 addresses the scenarios and research challenges; section 4 provides the methodology for implementing the research objectives; the business benefits of C2POWER based on the notion of cooperation are detailed in section 5; and the conclusion is section 6.

2. Objectives

The complexity of heterogeneous wireless networks and the battery powered handset devices connecting to them is driving new requirements in terms of power efficiency to ensure that battery life, environmental and thermal criteria can be met. In this context, C2POWER main objective is to research, develop and demonstrate energy saving technologies for multi-standard wireless mobile devices, exploiting the combination of cognitive radio and cooperative strategies, while still enabling the required performance in terms of data rate and QoS to support active applications. C2POWER project will investigate how cognition and cooperation can be extended to allow the system not only to manage shared spectrum, but to use context information ("knowledge") to decrease the overall energy consumption and radiated power of mobile devices while still enabling the required performance in terms of data rate and QoS.

The focus of the project includes two main components; one, the dominant, specifically dealing with technical aspects and the second one addressing business / management models related to the topic of the project and techniques under study.

At the **technical level** the main goal is to:

- Investigate how context information can be used by cooperative strategies to achieve power efficiency at the wireless interface of mobile devices and save battery lifetime.
- Investigate and demonstrate the potential of cooperative techniques based on advanced short range communications for the goal of power/battery lifetime saving of mobile wireless devices.
- Investigate and demonstrate minimum energy consumption handover procedures and policies between heterogeneous technologies and associated tradeoffs in realistic scenarios.
- Investigate, design and demonstrate energy efficient reconfigurable multi-standard transceivers (BB and RF) able to switch from one standard to another according to a power saving strategy.

At the management/ **business models** the main goal is to:

- Investigate methods and incentives to encourage cooperation among users/handsets and develop attractive business models for the network/service providers to stimulate and motivate cooperative networking among users and between heterogeneous networks.

As a consequence, the project should help emerging standardization groups to move the classical non cooperative paradigm, where the mobile device is a "terminal" entity towards a cooperative approach where cognitive devices are able to establish cooperation to save battery lifetime in heterogeneous environments. C2POWER will provide sufficient evidence on the technology and economic viability and its deployment.

3. C2POWER Scenarios and Research Challenges

As a starting point for the project, three main scenarios associated with different levels of cooperation and cognition have been defined:

3.1 Scenario 1: Power saving strategies using short range cooperative clusters in homogeneous networks

This scenario addresses a hybrid combination of infrastructure architecture and short-range cooperative network, as shown by Figure 1. Every terminal supports two air interfaces: a cellular\WLAN link and a short range link for exchanging packets locally. The cellular\centralized network can be UMTS, LTE, WiFi, WiMax or DVB and the short range links are based on low power technology (e.g. UWB, Bluetooth, Wibree, etc). Some mobile devices located in the proximity of each other decide to form a cooperative cluster, motivated by a power saving strategy or economic incentive. Mobile devices in the same cluster can communicate directly with each other using short range technology. Thanks to the spatial proximity and spatial diversity within a group of cooperative mobiles there is a high potential for power savings through a cooperative retransmission strategy. Cooperative diversity schemes and trade-off between power saving and the price of cooperation are open research topics to be investigated by the C2POWER project. A particular use case of this scenario is a cooperative strategy where power consumption is moved from one device to another motivated by a pay-off or other incentives based on business model that will be investigated.

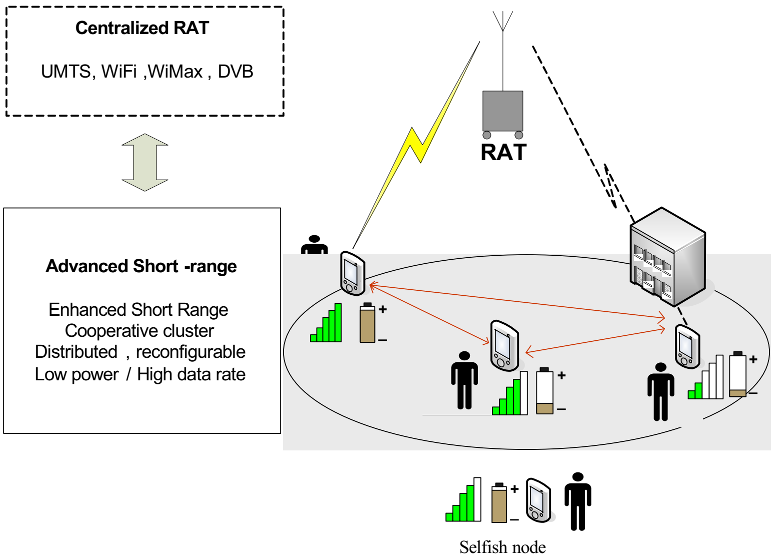


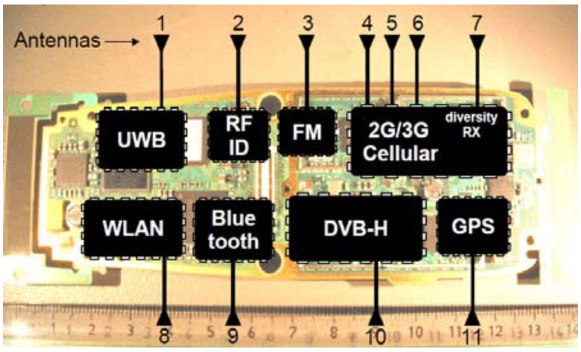
Figure 1: Cooperative cluster between nodes connected to the same RATs.

Here, the strategies are driven by the cognitive terminal embedded with support for both infrastructure network air interface and the low power short range technology. Hence spatial proximity among potential short-range cooperative partners can be identified through neighbour discovery process. By taking into account individual battery life time and the proximity information, relaying process among cooperative partners can be initiated if service performance is maintained and better power consumption is resulted. The signalling scheme and the relaying protocol for the short range links to facilitate the energy saving cooperation should be investigated and demonstrated through this application scenario. These strategies when implemented should allow the cognitive engine to make the right decision whether or not to initiate cooperative communication based on the foreseen trade off between cooperation cost and potential energy saving.

3.2 Scenario 2: Power saving strategies exploiting heterogeneous RATs

One of the most frequently mentioned characteristics of 4G is the ability to provide users with a continuous connection, or as it is typically referred to "always being connected". From the battery standpoint, this can also be interpreted as "always being drained". In fact, state of the art multi standard devices have high power requirements for maintaining two or more radio interfaces which reduces battery lifetime. For the variety of applications that need to be considered, latency and bandwidth requirements vary significantly depending on the applications in use, e.g., from infrequent low-bandwidth control messages to high bandwidth video streaming. Taking into account these varying bandwidth needs C2POWER will explore techniques that dynamically reduce power consumption for mobile devices without compromising network connectivity to the local infrastructure, communication range or limit the peak bandwidth needs of applications.

This scenario considers that several RATs are available in the location of a multi-standard mobile phone (see Figure 2). C2POWER will investigate strategies and algorithms that enable a system to switch among these interfaces, each with diverse radio characteristics and different ranges, in order to save power. It is pivotal to have energy efficient handover policies in place to provide the mobile user the best service experience conserving the optimal quality of services (QoS) in addition to the energy efficiency. As a part of this scenario, C2POWER will consider handover between macro and Femto-cells. This use case will contemplate the specificities of Femto-cells and handover to and from these cells as well as the improvements that can be achieved by introducing context information (can be multiple variables such as user location, habits, expected indoor movement, cell placing, room size...). This can provide better and more efficient algorithms, but also provide more realistic and predictive handover decisions.



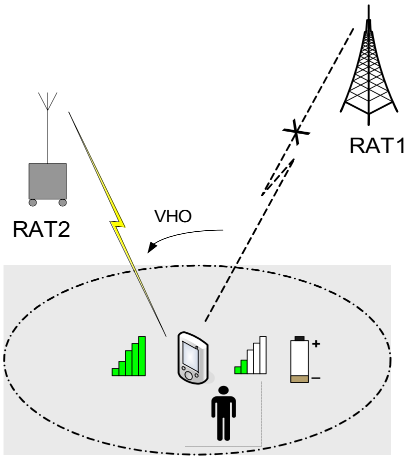


Figure 2 Multi-standard handset [6] and example of energy efficient vertical handover.

3.3 Scenario 3 (advanced or long-term): Power saving strategies using short range cooperation among heterogeneous nodes

This scenario envisages a more efficient use of the RATs available on a heterogeneous cluster which will be considered globally as a pool of opportunities rather than as independent technologies. In this way, Scenario 3 is a merger of energy saving features from Scenario 1 and Scenario 2, allowing cooperation among heterogeneous nodes as exemplified by Figure 3. In this example, Node B is initially connected to RAT2. Node B has low battery level and demands a service, e.g. video streaming, which, when offered by RAT2 entails high power consumption. Using context-awareness capabilities, Node B detects in its short range area Node A where RAT1 is available. RAT1 fulfills better the QoS required by Node B and additionally is more energy efficient. Thanks to a low-power short range interface, Node B invites Node A to establish cooperation. After some negotiation, e.g., motivated by a payment or a reputation mechanism, Node A agrees and a cooperative cluster is established. Node A connects to RAT1 and relays to node B the required packet data through the low-power short range link. The overall power consumption of the cooperative cluster decreases due to this strategy; obviously the power gain depends mainly on the energy efficiency of the short range link in this case.

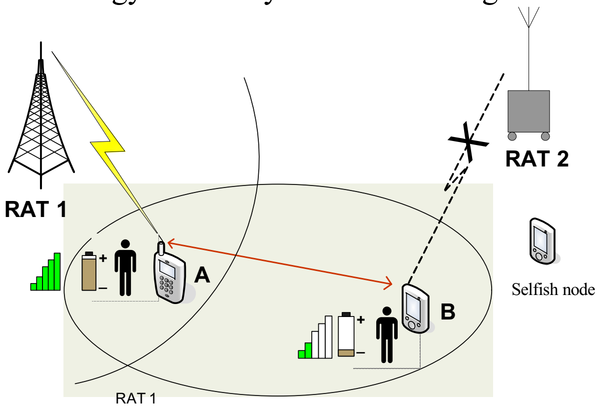


Figure 3 Cooperative cluster with nodes connected to heterogeneous RATs.

4. Methodology

The objectives within C2POWER will be implemented according to the scenarios defined and the end goal will be to design, develop and evaluate the algorithms that will be the enablers for energy efficient based on short-range cooperation and cognitive protocols/algorithms.

The architecture and algorithm design will progress along four collaborative tracks, with milestones that include the implementation of the key HW module/components that will be integrated in the proof-of-concept phase to demonstrate two major technology showcases on cooperative short range for power saving, and energy-efficient cognitive handover procedures. The methodology includes:

- **Context awareness and signalling for power saving strategies**: implementation and validation of energy efficient network and node discovery mechanisms.
- **Energy-efficient reconfigurable radio transceivers:** transceiver design that is multi-standard in nature and the hardware design must be ruled by energy savings, but with inherent flexibility; moreover, it is expected that switching from long distance communication to short distance can make use of antenna techniques that could even increase the transceiver's power efficiency.
- **Cooperative short range communications for power saving**: the study and definition of cooperative short-range communications for power saving, and the implementation of cooperative modules for the proof-of-concept phase. Under the umbrella of cooperative short-range technologies, algorithms/protocols to be studied are targeting:
    - Cooperative short-range networking based on Utility functions
    - Energy-efficient routing as the enabler for energy-efficient short range cooperation between nodes:
    - Cooperative Relaying for power saving
- **Energy-efficient cognitive handovers procedures and policies:** investigates energy-efficient cognitive handover algorithms (scenario 2) and implement and validates a

context-aware architecture (see Figure 4) for testing energy-efficient handovers in a heterogeneous networking environment for proof-of-concept.

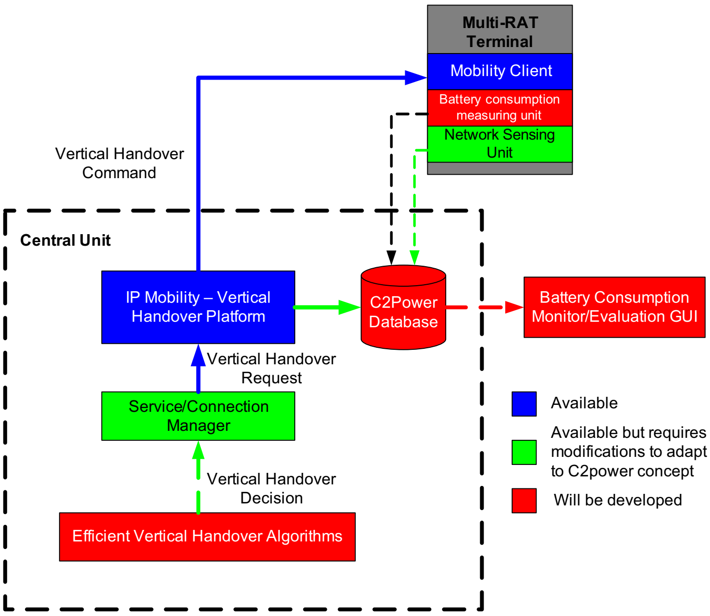


Figure 4 VHO experimental test-bed

- **Integration, and demonstration:** targeting the C2POWER proof of concepts for the showcases portraying cooperation in homogeneous networks (scenario 1) and the vertical handover for power saving (scenario 2). The showcases will be based on the C2POWER scenarios definition. To this end, this phase will integrate all the components developed in pervious phases to validate the project concepts on experimental testbeds for cooperative UWB and VHOs.

5. Business Benefits

C2POWER technology has the potential to open up new business opportunities for service providers and to accelerate the uptake of the next generation of network and service infrastructures.

One of the pivotal technologies in C2POWER is exploiting cooperation for power saving. Cooperation can promote attractive business models for the network/service provider as shown by Figure 5, that illustrates a scenario where a node sacrifices battery power to assist a nearby device motivated by a pay-off. A business opportunity for the network rises when implementing a centralized payment system to promote non-altruistic cooperation.

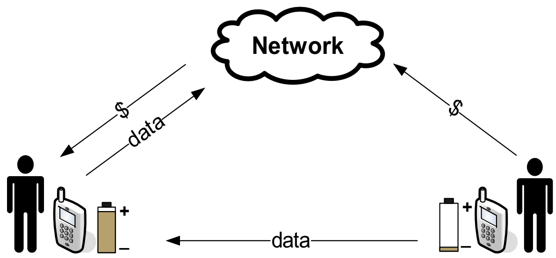


Figure 5 A device sacrifices battery power to assist a nearby device motivated by a pay-off (non-altruistic cooperation).

Reputation systems can provide a way to distinguishing cooperative from selfish nodes, to enable an informed decision about which nodes to choose from for future cooperation and which ones to avoid. Therefore there is a need to study and define reputation systems, which encourage responsibility and cooperation in opposition to selfishness. In addition, mechanisms and rules that guarantee fairness among the nodes will be investigated to avoid the collapse of cooperation and the well known "tragedy of the commons" phenomenon

Moreover, C2POWER has the potential to promote the take-up of beyond3G services and networks for manufactures and operators. A mobile user, whose terminal would be equipped with multiple RAT adapters, should be capable of vertically handing over between heterogeneous RATs in order to meet Quality of Service (QoS) or end to end Quality of Experience (QoE) requirements; however current battery technology provides limited lifetime. Without new approaches for energy saving, the 4G mobile users will leave searching for power outlets rather than network access, and becoming once again bound to a single location. This 4G "energy trap" will compromise the take off of 4G networks. C2POWER will contribute to decrease the growing gap between the energy of emerging radio systems and what can be achieved by battery technology evolution accelerating the uptake of 4G heterogeneous networks.

6. Conclusions

The energy required to keep mobile devices connected to the network over extended periods of time quickly dissipates, and battery technology is not sufficiently mature to anticipate existing and future demands for mobile power. Without any new approaches for energy saving, 4G mobile users will relentlessly be searching for power outlets rather than network access, and becoming once again bound to a single location. To avoid the 4G "energy trap" and to help wireless devices become more environment friendly, there is a clear need for disruptive strategies to address all aspects of power efficiency from the user devices through to the core infrastructure of the network and how these devices and equipment interact with each other. The ICT C2POWER project is the vehicle to address these issues through cognitive techniques and system cooperation. The cognitive aspect will consider context information as key resource exploited by cognitive enabled handsets that can learn and adapt their behaviour in order to save power by using the appropriate wireless interface for the current application workload. On the other hand, C2POWER project will also consider cooperation between mobile devices within a short range communication area through multi-hop communication.

Acknowledgment

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