Looking Beyond Green Cellular Networks

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Abstract—**This paper introduces a new network architecture for green cellular networks. The basic concept is to separate signaling and data in the wireless access network. Transmitting the signaling information separately maintains coverage even when the whole data network is adapted to the current load situation. Such network-wide adaptation can power-down base stations when no data transmission is needed and, thus, promises a tremendous increase in energy efficiency. On top of that, the signaling network keeps users connected while consuming only a fraction of the overall energy**

Keywords-component; Mobile Network Architecture, Future Generation Mobile Networks, Network Management, Signaling

I. INTRODUCTION

The increasing pervasiveness of the cellular wireless system and the well-known fact that base stations are particular energy hungry make the network devices for the last-hop consuming over 80% of the power used in the whole access network. Green Networking research, e.g., [1], takes the network's energy consumption into account. Despite the novelty of the topic, the research community has already produced interesting models and solutions to deal with the issue of energy-savings in communications and some of them are already being introduced in new products by device manufacturers. The current research activities can be grouped into the following three main tracks: i) improving access devices, ii) improving network deployments, and iii) changing the system management. Activities within the first group identified a huge potential for energy savings in the power amplifiers [2]. More energy can be saved by spending less power on unused wireless resources. In [3] the authors find that up to 97% of the wireless resources in OFDM systems are unused in access cells. A similar approach has been proposed for W-CDMA systems in [4]. Research activities within the second track, network deployments, exploit that shorter links can be operated at lower signal powers [5]. The third group, finally, performs network wide management by switching-off unnecessary access devices, e.g., when there are no active users to serve or if users can be served by other cells [6]. Since solving the network-wide optimization problem on the fly is computationally intractable, [7], mainly heuristics are proposed to decide which cell to be put in sleep mode [8], [9], and [10].

From analyzing the first group of these approaches, it can be concluded that improving the energy efficiency of devices will already do a very good job in reducing the overall energy consumption of wireless systems. However, they will not overcome the baseline power consumption of active base stations. This makes still attractive to power down systems when they are not loaded. The second group of approaches, new deployment strategies, adapt cell size to technology and traffic demands. However, these approaches do not adapt networks to the actually traffic load, e.g., by following daily and weekly traffic profiles. This is done by the third group of approaches – system level management. These approaches not only overcome the above limitations of earlier research areas, but add their gains on top of them. For instance, even a very efficient base station can still save energy when it is switched off. However, such network-wide adaptation adds high computational load and breaks the anytime-anywhere service paradigm of cellular networks by generating coverage holes.

The idea we propose falls in the third group of approaches and it is to separate the signaling between the mobile terminals and the access network from the data transmission. Following this approach, we can maintain *full-time* coverage while exploiting energy savings from powering down cells. Since signaling alone generates only low data-rates, the signaling access can be designed for high energy efficiency and coverage. This includes choosing an adequate MAC and PHY layer technology for long range, low data rate systems and only using a small amount of the spectrum. Data cells will still be optimized for high data rates at shorter ranges in order to cope with the current and future traffic demands.

With this paper we introduce the key features of this concept and its main directions. Moreover, we critically discuss its potential and the research challenges to design practical systems that separate data from signaling.

II. LIMITATIONS TO ENERGY MANAGEMENT IN CELLULAR NETWORK

Energy management strategies are currently being investigated for several wireless technologies by the research community, e.g., [11], and some energy saving mechanisms are currently available in commercial products. The basic idea behind these strategies is that of exploiting the spare capacity available in cellular networks when traffic is low in order to set a subset of base stations to an inactive low-power mode (Figure 1). This is motivated by the typical energy consumption profile of base station equipments that is characterized by a remarkable difference between the minimum power of the active mode and the power of the sleep/inactive mode.

Improvements in the technologies and components of base station equipments that are being investigated will allow in the future to reduce the power consumption of all different types of devices. However, since the possible improvements on the hardware energy efficiency are limited by the baseline power consumption of active base stations, one has to recur to other means. Therefore, energy management strategies at system level will be the only viable approach in order to achieve an energy profile of the network that is proportional to traffic load.

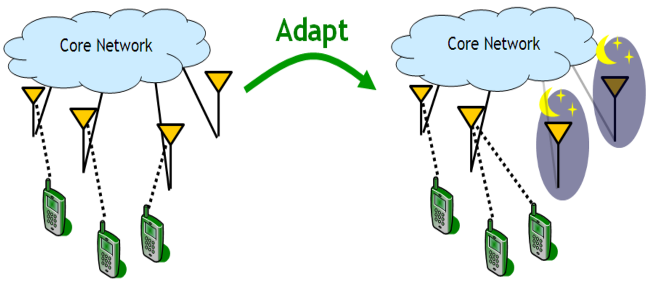

Figure 1: Energy management concept in cellular networks

The ideal energy behavior we may wish from an energy management strategy is a power consumption of the whole system that is linearly dependent on the traffic load from very low with no traffic to maximum value with full load (Figure 2). If we were able to achieve this ideal behavior we could simply add any technology improvement to those of the energy management. Unfortunately, there are some limiting constraints of the traditional cellular architecture that has been used so far for all wireless access technologies that prevent an optimal power management and, more in general, to reach very high reductions of the energy consumption.

The cellular architecture of wireless access networks has its foundation on the concept of full coverage of the service area that ensures that user terminals in any point of the area can get access to the network at all times. The maximum coverage area that can be potentially covered by a base station depends on several issues, including the transmission power and the propagation conditions. Where traffic density is low, cell layouts commonly adopted are usually driven by the full coverage need and coverage ranges of base stations tend to be almost fully exploited by limiting the overlap among neighboring cells to what is necessary for the mobility management. In areas where traffic is much higher, base station density is highly increased in order to reduce cell size and increase the available access capacity per unit area. As a result, the cellular layout is characterized by a redundant coverage where each point in the service area is covered by several base stations.

It is quite evident that energy management procedures in traditional cellular architectures can only exploit, when traffic is low, the redundant coverage of the network that is used to provide enough capacity when traffic is high. However, since full coverage must be ensured at all time, a non-negligible part of the network can never be switched off even if there is no active user.

It has been shown that potential energy savings achievable with energy management strategies in current cellular technologies are in the range of 20%-40%, depending on the considered traffic profiles and network layouts [9]. Paradoxically, this savings may even reduce (in percentage) in the future with the new cellular architectures based on micro cells. Indeed, it is commonly accepted that these micro-cellular layouts can reduce the nominal consumption since the energy per covered area of micro base stations is lower than that of macro base stations. Unfortunately, since micro cells provide high capacity with limited coverage overlap, they leave little room for energy management since basically all cells are essential for guaranteeing full coverage.

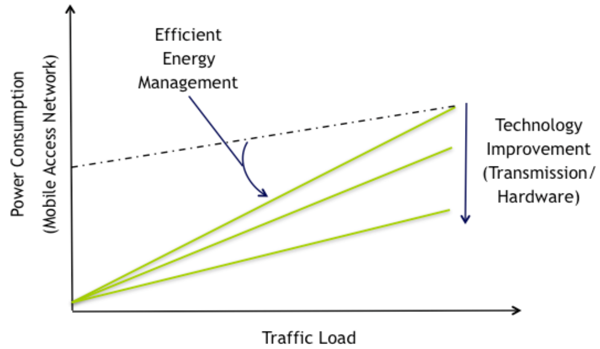

Figure 2: Impact of network management and technologies on energy performance

Therefore, the ideal behavior shown in Figure 2 cannot be achieved with the traditional cellular architecture of current wireless access systems. We argue that this requires a paradigm shift that is able to completely reshape the structure of the network and provide revolutionary ways of ensuring ubiquitous wireless access to communication networks.

III. COVERAGE ON DEMAND FOR HIGH ENERGY EFFICIENCY

In light of the issues mentioned in the previous section, we work on a different network architecture that supports efficient network adaptation and still satisfies the constraint of "always connected". This paradigm shift is grounded on the following questioning:

1. What is necessary in order to allow a high degree of adaptation of base stations modes (including sleep modes) and still allow the full time and ubiquitous connection between users and network?
2. Does the signaling transmission (i.e. architecture and radio interface) have to be designed in the same fashion as the data transmission?

The discussion on the first question leads to the consideration that not much information needs to be transmitted in order to enable the "always connected" behavior. One has only to provide signaling information to allow the mobile to be paged and to reach the network when it is desired. Consequently, the investigation of the second question leads to the conclusion that signaling and data networks should be separated. The separation provides two advantages. First, base stations for data access can be switched off when no user is currently active.

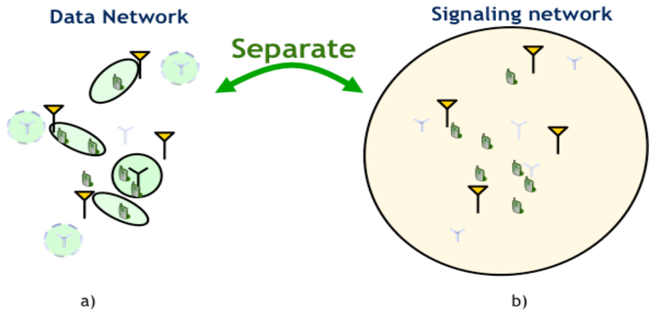

Figure 3: Data and signaling network operation

Second, signaling base stations, which are only in charge of the "always connected" signaling service, can be designed for low-data rates and long-range transmissions. That is clearly more efficient that the current mixing between data and signaling transmissions.

Potential gains from this separation between signaling and data, as proposed in Figure 3, must be investigated. Figure 3a shows how the data network behaves. At the areas where no user is currently active, no signal from any data access point is provided in order to avoid the waste of radio resources. Figure 3b depicts the signaling nodes that allow coverage for the non-active spots in case some user becomes active. The idea is that on one hand, the radio for the access points is designed for high data rates and the network is flexible and smart. On the other hand, the signaling network is fixed in other to guarantee the coverage in the whole area and the radio devices are designed to be energy efficient for low data rates and long-range transmissions. Clearly, a considerable amount of technical issues arise from this new approach due to the interaction between signaling and data networks that calls for a renovated research effort in mobile networks. We believe that this way of thinking wireless networks is the only viable approach to allow significant reduction on the energy consumption of networks as a whole and still be able to cope with high quality of service requirements. In the next section we further discuss the technical challenges involved with this new architecture.

IV. TECHNICAL CHALLENGES

The implementation of this brand new architecture requires a research effort to tackle several technical challenges on different issues. In the following we point out and comment these challenges and, whenever relevant, discuss how they are related to the additional advantages mentioned above.

Context Awareness - Traditional signaling mechanisms adopted by current cellular technologies interact with user terminals to get information on the service requests and with the network elements necessary to provide the service. At the radio interface, the user terminal issues service requests to the same base station that then allocates the resources to serve the requests. Differently, the signaling network of the new architecture needs to get more information from the users due to the separation of the signaling base station that receives user requests and the base station of the data network that then allocates resources. This richer information is required in order to characterize what can be called the "context" of a service request. The context is the key element that allows the signaling network to activate appropriate resource selection algorithms for the data network.

A first and fundamental information to be included in the context is the user terminal location with respect to access points that can potentially serve its request. This is obviously not necessary in traditional systems since the base station that gets the service request is the same that serves it.

Position information may not be sufficient to identify the most appropriate base station since the quality of the radio channel among user terminal and closest base station may be poor due to obstacles and propagation impairments. It is therefore necessary to map appropriately the location information to estimations of the quality of radio channels with base stations in the visited area. The system can use for example measurements provided by the terminals during active data sessions, which can be stored together with positions and then used for future requests.

Not only the location of user terminal at the moment of the service request, but also its estimated mobility can be an important element to characterize the context. Information on user mobility can help to identify the base station to activate on the trajectory, avoiding for instance to select a cell that with high probability will be quickly left by the terminal during its movement.

Resource Management - Resource management is in charge of selecting and allocating the radio resources necessary to serve a user request at the base station where the request has been addressed.

Resource selection procedures are a key component of the new architecture to reduce the energy consumption since they determine the energy state of network devices. Resource selection needs to take into account not only the context information on the service request, but also the status of the network and their devices.

Generally speaking, the selection and (if required) activation of a base station able to serve a user request given the context information discussed above may not be a difficult task. Unfortunately, optimizing this decision process is much more complicated. Even the identification of an optimization objective is not easy, due to the obvious tradeoff between energy cost and performance and the number of constraints involved for quality of service requirements, terminal capability limitations, technologies of base stations in range, and available radio resources.

Resource management is naturally an online decision process and the incremental energy cost for the assignment of a service request to a base station depends on its status. If the base station is already active the incremental cost for serving and additional user is usually much smaller than in the case when it is in sleep mode and needs to be reactivated. When mobility is an important issue of the user context, algorithms for resource activation and management need to orchestrate the selection of a sequence of base stations following the movement of the user.

Heterogeneous[1] data networks – The basic concept of the new architecture is independent from the wireless technology adopted for the data network even if only future generation low-power wireless technologies will allow to achieve very high energy efficiency that is main target of the new architecture. But more than that, it is worth pointing out that the new architecture enables a flexible management of a set of heterogeneous data networks using different wireless technologies.

The lifecycle of wireless technologies is much longer than it was expected. A high fraction of mobile voice calls is still handled by the old GSM technology in many countries. Most of mobile handhelds have today multiple radio interfaces with different technologies and even base station equipments are currently being replaced with multi-technology devices attached to a single radio access network. Dealing with the coexistence of heterogeneous wireless technologies is

[1] Notice that Heterogeneous here does not refer to the HetNets networks defined in 3GPP, where different types of cells (i.e. Macro, Micro, etc…) are employed. Here we refer to different radio access technologies.

somehow unavoidable and it is commonly recognized as a key element for the design of future generation mobile network architectures.

The new architecture is particularly suitable for managing heterogeneous wireless technologies as it reverses the classical approach to network selection. Since the access to communication service is mediated by the signaling network, it is no longer the user terminal that selects the access point, but this is basically delegated to the network. This allows a more flexible and intelligent management of traffic with the set of technologies and radio resources available through algorithms that are able to take into account the status of the whole system. The design of these new algorithms is an interesting technical challenge since several issues can be considered including specific mobility and resource management policies of mobile operators.

Radio Technologies for the Signaling access – The signaling network proposed here for the new architecture has very unique characteristics, such as robustness, low energy consumption, long range, and low data rates. Therefore, the design of such network requires a paradigm shift from the traditional approaches and it is probably one of the hardest technical challenges.

As for radio spectrum resources, the need to create relative large coverage areas for signaling base stations suggests to use low frequencies that have better propagation conditions and obstacle penetration. The need to minimize energy consumption tends to privilege time based access scheme that allows a better power management according to traffic level. Multiple antenna technologies can also be exploited to improve energy performance and, if necessary, to support the localization service for the context information.

At the architecture level, several solutions are possible ranging from extreme scenarios where all signaling functionalities for the management of data sessions are implemented in the new overlay signaling network, to hybrid cases where only session setup is managed by the signaling network, while session control is delegated to data network like in current wireless systems. In any case, the communication and integration among control functions in the data networks and the signaling network is a critical part of the system design that needs to be addressed.

As far as the mobility management is concerned, the signaling network offers new opportunities to improve efficiency. It is worth mentioning here that this is particularly relevant in the presence of network layouts with very small cells that are able to provide very high broadband access capacity per unit area and energy efficiency. With traditional technologies the main limiting factor that prevents to use very small cells is obviously mobility management that requires quick handover procedures. With a separated signaling network, performance requirements on handover procedures can be relaxed since decisions can be taken in advance and communicated to user terminal via a robust radio channel.

Network Planning – The planning has to account with the spatial-temporal load profile throughout the network. An efficient network design must not only take into account the energy management, but also jointly considers both deployment and operational costs.

A final remark is on the concept of coverage. Traditionally, a user is defined to be covered if it can receive the pilot signal of at least one access point. However, other coverage definitions can be applied in this new approach, f.i., a covered user could be a user that can inform a signaling device of its connection request and communicate with at least one assigned data access point. The new architecture leaves room for even more extreme coverage definition where a user is covered if it can only receive a transmission from a signaling access point within a given time interval and communicate with at least one access point. This also opens the problem of designing optimized activity patterns for signaling network devices.

V. Conclusion

This paper introduced a new network architecture for green cellular networks. The basic concept is the separation of signaling and data in the network. The independent signaling network is a promising solution that provides freedom for data transmission adaptation. This solution is very energy efficient since the data access points do not waste transmitted power on areas without active users. Several technical challenges were identified in this paper such as context extraction, resource management and the design of a new architecture and radio format for the signaling network. These challenges open the need and opportunity for new research on the field.

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