Reduced Power Consumption for 3GPP-Compliant Continua Health Devices by Deployment of Femtocells in the Home Environment

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Abstract. The Continua reference architecture is now widely considered to be the *de facto* framework for implementation of personal telehealth systems. Existing Continua guidelines specify the use of personal or local area network technologies (Bluetooth, USB, ZigBee) for personal health device connectivity within the monitored person's local environment. However, there are now efforts to update the Continua reference architecture to include personal health devices with integrated 3GPP radio interfaces (GPRS, HSPA, LTE etc.). To that end, indoor femtocell home gateways provide several benefits for personal telehealth systems with such 3GPP-compliant Continua health devices. A notable benefit is the reduced power consumption by the devices compared to case where connectivity is via outdoor macro base stations. This paper supports this premise with some results from comparative simulations between femto- and macro-based implementations of the Continua personal telehealth systems.

Keywords: Personal Teleheath, Femtocells, Power Consumption, Energy Efficiency, Machine-Type Communications, Continua.

1 Introduction

The Continua Health Alliance[1] (henceforth, referred to simply as "Continua") is arguably the leading open industry group providing interoperability guidelines and certification programs for the implementation of personal telehealth systems. The guidelines specify an end-to-end harmonized Continua reference architecture to represent the high-level structure of personal telehealth systems and provide commonly-agreed terminology for different health device classes and system interfaces [1]. Legacy Continua devices in the patient's domain currently use Bluetooth, Universal Serial Bus (USB) or Zigbee standards for data transport[1], and the baseline IEEE 11073 Personal Health Data (PHD) standards for interoperable data formatting, session control and so on [2]. The next generation of Continua health

[1] Continua Health Alliance: http://www.continuaalliance.org/

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devices may also include Third Generation Partnership Project (3GPP) standardized radio interfaces (GSM/GPRS, HSPA, LTE, etc.).[2]

The 3GPP-compliant Continua health devices extend direct mobile network connectivity to personal telehealth systems allowing for remote device management (e.g. fault management). Furthermore, it exposes mobile operator service APIs (e.g. location based services), subscriber-related data repositories (e.g. Home Subscriber Server) and billing platforms, thus enabling development of innovative personal telehealth services and business models [4]. However, the radio access links from indoor located 3GPP-compliant Continua health devices would typically terminate at an outdoor base station located kilometers away. This means in order to achieve radio performance targets (e.g. Signal to Interference and Noise Ratio) higher device transmit powers are needed to compensate for the distant-dependent path losses, attenuation through building walls and co-channel interference [5]. This will in-turn necessitate more frequent battery recharging or replacement for portable personal health devices, a scenario that should be avoided, particularly for elderly patients living independently with frail physical and/or cognitive capabilities, or for cases where health device downtime may have serious ramifications.

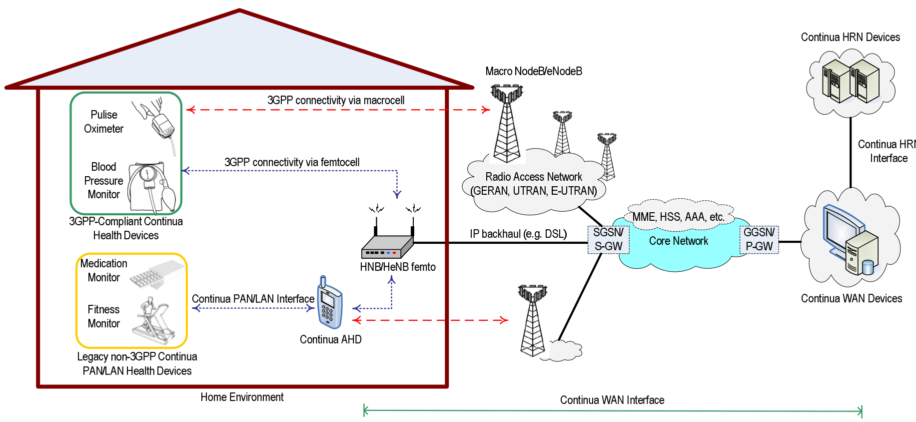
Subscriber-deployed miniature indoor base stations or femtocells [3] may provide several benefits (one being reduction in required device transmit powers) when implemented as gateways for personal telehealth systems [4]. In this paper, we present comparative simulations between the femto- and macrocellular scenarios that quantify the possible power savings (prolonged battery lifetimes) for 3GPP-compliant devices in Continua personal telehealth systems. The remainder of the paper is organized as follows. Section 2 provides a background on femtocells and potential benefits in personal telehealth systems, while Section 3 outlines the system model that is adopted for the study. Section 4 describes the simulation methodology and results, while concluding remarks are presented in Section 5.

2 Usage of Femtocell for Personal Telehealth Systems

As more information gathering and processing functionality is increasingly embedded in everyday objects, the need for converged home gateways for horizontal integration and management of disparate networked home systems (for telehealth, smart metering, home security, etc.) becomes more acute. To that end, femtocell technologies provide an attractive way for implementing the converged gateway for the systems, such as, the personal telehealth system discussed in this paper. Access to femtocellular services (voice, mobile data etc.) is usually restricted to a closed subscriber group (CSG), such as, household members. Femto base stations that operate in the 3GPP Universal Mobile Telecommunication System (UMTS) and Long-Term Evolution (LTE) environments are known as, Home Node Bs (HNBs) and Home eNodeBs (HeNBs), respectively [3]. These terminologies provide distinction from the NodeB and eNodeB terms used for UMTS and LTE macro base stations, respectively.

[2] The Global Certification Forum (GCF) certifies 3GPP-compliant mobile devices and has announced in early 2011 a partnership with Continua on joint certification of 3GPP-compliant devices: http://www.globalcertificationforum.org/WebSite/public/continua.aspx

Figure 1 illustrates a simplified end-to-end high-level view of heterogeneous macrocell and femtocell deployments to support a Continua personal telehealth system. Mobile network connectivity for 3GPP-compliant Continua health devices is possible via a macro nodeB (or eNodeB) located outdoors, or alternatively via a femto HNB (HeNB) deployed within the home environment. On the other hand, mobile network connectivity for legacy Continua Personal Area and Local Area Network (PAN/LAN) health devices is enabled on the first hop via a Continua Application Hosting Device (AHD), such as, a Smartphone, which provides Continua PAN/LAN interfaces towards the health devices and 3GPP interfaces towards the macro or femtocullar mobile network. From the mobile core network perspective, all 3GPP-compliant Continua personal health devices and AHDs devices are viewed as 3GPP user equipment (UE). Henceforth, the term UE will be used to refer to any of those aforementioned 3GPP-compliant Continua devices.



Notes: AAA = Accounting, Authentication and Authorization, AHD = Application Hosting Device, DSL = Digital Subscriber Line, E-UTRAN = Evolved UMTS RAN, GERAN = GSM Edge Radio Access Network, GGSN = Gateway GPRS Support Node, GPRS = General Packet Radio Service, GSM = Global System for Mobile, HRN = Health Reporting Network, HSS = Home Subscriber Server, IP = Internet Protocol, LAN = Local Area Network, LTE = Long Term Evolution, MME = Mobility Management Entity, PAN = Personal Area Network, P-GW = Packet Data Network Gateway, RAN = Radio Access Network, SGSN = Serving GPRS Support Node, S-GW = Serving Gateway, UMTS = Universal Mobile Telecommunications System, UTRAN = UMTS RAN, WAN = Wide Area Network, WCDMA = Wideband Code Division Multiple Access, 3GPP = Third Generation Partnership Project.

Fig. 1. High-level view of MTC and femtocell utilization for implementing the Continua personal telehealth system

The use of femtocells, as illustrated in Figure 1, provides additional benefits for 3GPP-compliant Continua personal telehealth systems, such as [4]:

- Enhanced access control strategies by the management of the femtocell CSG restrictions for personal health devices, temporary care givers etc.;
- Improved indoor coverage and capacity, ensuring service availability even usual macro coverage dead spots (e.g. attic) and scalability in terms of achievable throughput;
- Exposure of APIs for value-added services (e.g. virtual fridge notes for medicine reminders) that exploit femtocell awareness information of devices and subscribers within their coverage areas [6];

- Enhanced local area internetworking among home devices by implementation of multi-radio femtocell designs[3] and Local IP Access (LIPA) traffic breakout to alleviates congestion of macrocellular networks [7];
- Reduced device power consumption (less device uplink transmit power requirements) compared to macrocellular case.

This paper provides a more detailed simulation study of the reduced power consumption benefit enabled by femtocell connectivity.

3 System Model

The radio frequency (RF) uplink models are useful for the study of transmission power requirements (hence power consumption) of wireless health devices. The typical building blocks for a 3GPP-compliant mobile wireless device include integrated circuits for RF, baseband and mixed-signal processing functions [9, 10]. Each of the functional blocks contributes to the overall budget for power consumption of the device. To that end, the majority of power consumption budget is attributed to the RF transceiver and modem circuitry [10, 11]. The fraction of RF components power consumption is even more significant in wireless embedded devices that would usually have relatively less as or no user interface components (microphones, speakers, backlit displays, etc.) and reduced set of integrated secondary radio interfaces (Bluetooth, GPS, NFC, etc.).

An LTE radio access environment is assumed in this study, as there are ongoing efforts within 3GPP to modify features (e.g., signaling) in LTE, and evolutions beyond, for the impending proliferation of a large number of 3GPP embedded wireless devices [8]. In LTE networks the UE that are ON may be in either Radio Resource Control (RRC) connected or RRC idle state depending on whether the UE context is registered at a serving (H)eNB or not [5]. In the `RRC_Connected` state, the UE transfers (or receives) data packets, monitors the shared signaling channels for any scheduled resource allocation and provides measurement report feedback to the (H)eNB. By contrast, no transmission (or reception) of user data occurs in the `RRC_Idle` state except for periodic monitoring of common signaling and paging channels,. This inactivity in `RRC_Idle` state allows for most of the device circuitry to be powered down (sleep mode) so as to prolong battery life. Battery conserving opportunities can also be obtained by exploiting inactive periods in the `RRC_Connected` state (e.g. due to bursty traffic) [12]. Reduction of transmit power by reducing radio link distance provides even higher savings in power consumption in `RRC_Connected` state [13] and is the focus of this paper.

The LTE uplink adopts Single-Carrier Frequency-Division Multiple Access (SC-FDMA) as the radio interface. The SC-FDMA scheme maintains a low Peak-to-Average Power Ratio (PAPR) thus reducing UE power consumption, and also provides the benefit of high frequency efficiency due to compact subcarrier spacing [5].

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[3] Example: Argela Femtocell and Home Gateway integrates both 3GPP (WCDMA/HSPA) and non-3GPP (WiFi, ZigBee) interfaces: http://www.argela.com/solutions.php?cid=femtocell

The total system bandwidth W is divided into subcarriers with an inter-carrier spacing 15kHz. Twelve subcarriers with 180 kHz bandwidth in total are grouped into a physical resource block (PRB) with 0.5 ms temporal duration, which is the basic radio resource unit allocated to UE. In this study, we assume the base station scheduler operates in a round-robin manner. The radio propagation between UE and (H)eNB experiences path losses including distance dependent path loss, shadowing and fast fading. The penetration loss due to walls separating the apartments is explicitly modelled, while penetration loss due to internal walls within the apartment is taken into account by using a log-linear model that depends on the separation distance. In this paper, we adopt the 3GPP TR 36.814 channel models [14], to evaluate the path loss PL for all possible radio propagation scenarios, namely: indoor UE to HeNB, outdoor UE to eNB, indoor UE to eNB, and outdoor UE to HeNB propagation.

The UE uplink transmission power is determined by the 3GPP fractional power control method for the Physical Uplink Shared Channel (PUSCH) that bears the LTE uplink user data. We use a similar approach to that proposed in [15], by ignoring the closed-loop corrections which results in the following open-loop power control scheme where the UE transmit power P_t is expressed as:

$$P_t=\min\{P_{max}, P_0+10\log_{10}M+\alpha PL\} \quad (1)$$

where P_{max} is the maximum UE transmit power, P_0 is a UE- or cell-specific parameter indicating the possible minimum UE transmit power, M is the number of PRBs assigned for a certain UE, α is the cell-specific path-loss compensation factor, and PL is downlink path loss estimated by the UE. The uplink performance is measured by investigating the UE uplink throughput by summing the data throughput over all the PRBs allocated to the UE. The throughput over PRB j is calculated by mapping the signal-to-interference plus noise ratio (SINR) on PRB j with the equations,

$$S_j = \begin{cases} 0 & SINR_j \le SINR_{\min} \\ BW_{PRB} \cdot BW_{eff} \log_2\left(1 + SINR_j / SINR_{eff}\right) & SINR_{\min} \le SINR_j \le SINR_{\max} \\ S_{\max} & SINR_j \ge SINR_{\max} \end{cases} \quad (2)$$

where BW_{PRB} is the bandwidth of a single PRB, BW_{eff} and $SINR_{eff}$ are bandwidth and SINR efficiencies that represent capacity loss due to system implementation and signal processing procedures. The link-level throughput mapping (2) was initially proposed in [16] and the parameters BW_{eff} and $SINR_{eff}$ are aligned with 3GPP TR 36.942 [17] and are also listed in simulation parameters Table 1 of next Section.

4 Simulation Methodology and Results

The simulated environment was covered by an overlaying macrocellular network composed of seven uniformly placed eNB sites as shown in Figure 2. Each site covers three hexagonal sectors using sectorized antennas and maintains separate radio resource management procedures. The eNBs provide universal radio access services to all registered subscribers. In the central cell, one large residence building is modelled either at cell centre or cell edge (see Figure 2, inset). The building has $100m^2$ apartments arranged in a 5x5 grid layout that is commonly used in 3GPP simulation studies [18]. Furthermore, each apartment may have either one or no HeNB deployed, and the HeNBs operate in same spectrum band as the macro eNBs.

The system simulation parameters are listed in Table 1 and are in line with 3GPP simulation guidelines outlined in [14]. Comparative studies of the macro and femto systems were performed using a Matlab static simulator over a large number (10^4) of random snapshots (Figure 2 being an example snapshot). For each snapshot, the positions of the UE (both indoor and outdoor) and HeNBs (indoor) were generated randomly and the performance metrics evaluated.

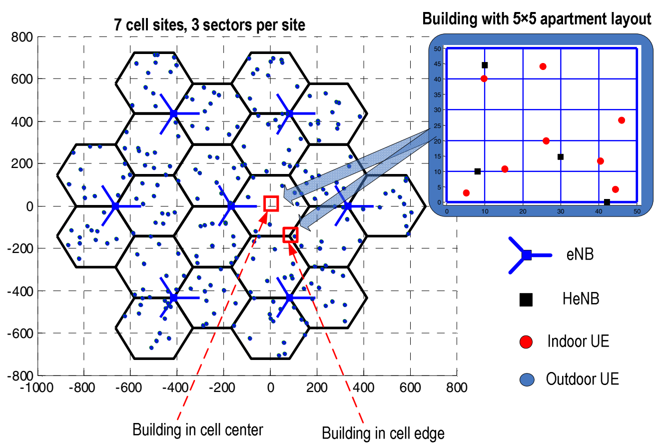

Fig. 2. Macro- and femtocellular system layout

Table 1. Simulation parameters

Parameter	**Value**
System Parameters	
Inter-site Distance	3GPP Macro Case 1: 500m
Carrier Frequency	2 GHz
Bandwidth	10 MHz, 48 PRBs for data+2 PRBs for signalling
Bandwidth Efficiency	0.4
SINR Efficiency	1
Thermal Noise PSD	-174 dBm/Hz
(H)eNB Parameters	
eNB Antenna Gain	14 dBi
Received Noise Figure	7 dB
Antenna Pattern	eNB: $A(\theta) = -\min[12 (\theta/ \theta_{3dB})^2, A_m]$ $\theta_{3dB} = 70^o$ and $A_m = 20$ dB
	HeNB: Omni-directional
UE Parameters	
Maximum Transmit Power	23 dBm
Maximum Antenna Gain	0 dBi

The generated cumulative distribution function (CDF) plots of the average UE transmission power for the scenarios where the indoor UEs (Continua health devices) are connected via the eNB and the HeNB are shown in Figure 3 (left). For the HeNB case, simulations are run for different values of power control parameter P_0 so as to observe transmission power requirements for different power control scenarios. For the eNB, simulations are repeated for the scenario where the building is in cell edge and cell center. Considering same combination of power control parameters (P_0 = -73 dBm and α = 0.8) for eNB and HeNB in Figure 4, the UE connection via the HeNB can provide 50%-ile UE transmission power saving of 39 dB. To put that power saving into perspective using a simple example, an alkaline AAA-size cell (1.41 Wh capacity) could potentially increase its lifetime by 2-3 orders of magnitude.

Figure 4 (right) shows the CDFs for the average achievable UE throughputs for the same set of simulation runs. The results demonstrate ten-fold 50%-ile throughput increase even for the case of UE with lower power (P_0 = -83 dBm and -93 dBm, with α = 0.8). For typical periodic and bursty telemetry traffic from monitoring devices, a higher throughput reduces the amount of time the UE remains in connected state, which in turn reduces power consumption [19]. This benefit becomes more significant for cases with increased volumes of telemetric data (e.g. video clips).

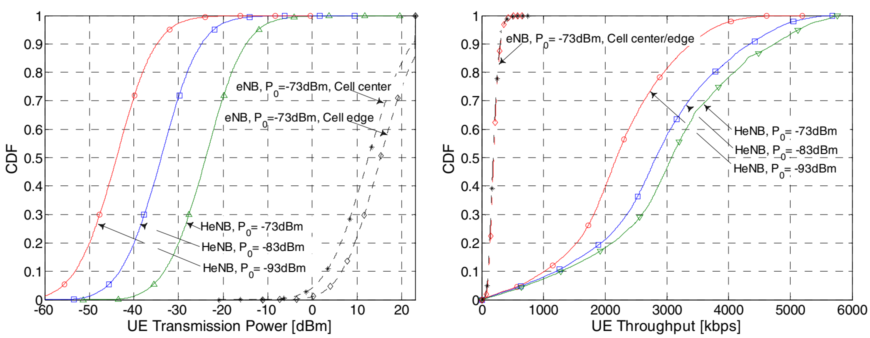

Fig. 3. CDFs of average UE transmission power (left) and throughput (right)

5 Conclusions

This paper studied the potential device power consumption reduction benefit enabled by femtocells in the implementation of Continua personal telehealth system. To that end, we obtained simulation results for a given case study that indicated significant device transmit power savings for a femto-based system compared to an equivalent macro-based personal telehealth system. We plan to continue study with further elaborate simulations that for instance take into account real traffic patterns of commercial off-the-shelf personal health devices. Furthermore, we intend to reproduce the teleheath system setup in a femtocell testbed to obtain even more realistic evidence of the power saving benefits and demonstrate other femtocell features that add value to personal telehealth use cases.

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