# Next Generation Femtocells: An Enabler for High Efficiency Multimedia Transmission

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**Abstract**
The first generation of femtocells is evolving to the next generation with many more capabilities in terms of better utilisation of radio resources and support of high data rates. It is thus logical to conjecture that with these abilities and their inherent suitability for home environment, they stand out as an ideal enabler for delivery of high efficiency multimedia services. This paper presents a comprehensive vision towards this objective and extends the concept of femtocells from indoor to outdoor environments, and strongly couples femtocells to emergency and safety services. It also presents and identifies relevant issues and challenges that have to be overcome in realization of this vision.

## 1. Introduction

Femtocells are already appearing in the market for some specific applications such as coverage hole fillers. Nevertheless their true potential is yet to be fully exploited. On one hand they provide fixed-mobile convergence, thereby bringing several benefits to the end user such as ubiquitous service provision, and also to the mobile cellular operator such as off-loading the load on macro network, better indoors coverage, better spectral efficiency through small cell-sizes and of course capturing a portion of the fixed-line market. They can also act as a true enabler for high efficiency multimedia transmission such as next generation high definition (HD) streaming that requires very high data rates and constrained delay performance. Existing systems can start to support multimedia traffic, however they are limited to low numbers of users, situated close to basestations, and with low mobility. Theoretically femtocells enable the whole capacity of a sector/cell inside user premises (practically it would depend upon efficiency of interference management between macro and femto network) assuming enough capacity is available on the wired backhaul, which is not a major problem given the advances in wire line technology. According to studies in [1], there has already been a 1600x increase in spectral efficiency since 1957, due to the spatial reuse afforded by reduced cell sizes and transmit distance. With the further reduction in cell size, and additional isolation arising from in-building operation in many femtocell scenarios, this trend is expected to continue, with great benefit for high capacity services such as multimedia. Despite their potential, femtocells still have some issues to overcome such as interference management, latency problems due to backhaul via internet (which is quite important for delay sensitive multimedia services), and handover signalling and multimedia stream routing to support mobility.

In this letter, we present a vision in which femtocells act as a key enabler for broadband multimedia services for both indoor and outdoor environments. We also present associated challenges and opportunities to achieve these goals.

## 2. Vision

Our vision of femtocells envisage a device or access point that is not only capable of broadband transmission for bandwidth hungry multimedia services but also capable of efficient transmission of low data rates with low duty cycle by way of machine to machine (M2M) communication with machines or sensor nodes in the local neighbourhood. Furthermore, a uniform solution is envisaged by extending the concept of classical femtocells from indoors to outdoors where they could act as fixed or mobile relay stations [2] with the difference that the backhaul is wireless for the latter. Moving femtocells will also address the problem of serving multimedia traffic to highly mobile users. For all these cases, we consider self-organisation (self-x) and self-optimisation to be an integral feature of femtocells as the scale of their deployment could be huge and without self-x operation the network management, optimisation and its evolution would simply not be feasible. Fig. 1 illustrates the above described vision with some examples from real life and shows that the femtocell is not only providing high efficiency interactive and HD streaming multimedia services

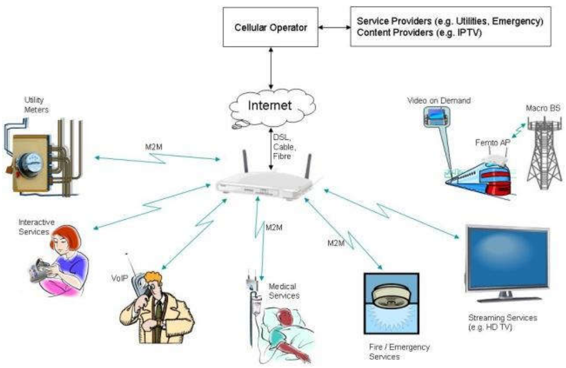


Fig. 1. Vision

but can also have M2M communication for various applications such as utility meter readings and automatic transmission to the utility provider, interface with the fire alarm and in case of a fire event autonomous communication with emergency services, and communicating the sensor data from a patient to corresponding medical services. Infact, femtocells can provide a new paradigm of safety and emergency services such as requesting multimedia rich feedback and rapid reaction beyond, for example, a typical simple localization service. This is particularly important for the care and safety of vulnerable persons such as elderly people and children.

The vision figure also illustrates the use of femto access points in outdoor areas, for example in moving passenger vehicles for provision of high efficiency video on demand (VoD) services with backhaul through the wide area cellular operator.

### 3. Opportunities and Challenges from Radio Access Perspective

This section discusses the vision presented in section 2 from radio access perspective.

- **Flexible Air Interface.** Since the presented vision encapsulates transmission of a variety of multimedia data, it implies the air interface should be flexible to accommodate efficient transmission of each. At present, no single air-interface is optimised for efficient transmission of both high speed data (e.g. for broadcast streaming) as well as low speed data for M2M communication. However, for typical home applications, interactive and streaming services are expected to be dominant, thus M2M communication may take place by piggybacking on existing air interfaces such as the 3GPP LTE/ LTE-Advanced air interface that are quite suitable for broadcast and multicast services as well.

- **Interference Aware Resource Allocation.** Since the majority of multimedia services like streaming or interactive gaming are delay-sensitive (which in the case of femto networks is even more critical due to their inherent dependability on the internet), the instantaneous quality of service (QoS) requirements (particularly latency) should be satisfied irrespective of the radio environment. Service degradation is highly likely to happen due to inter-cell interference (ICI) [3]. In femtocell networks, the ICI may originate from other femtocells (co-tier) or the macro cell(s) (cross-tier) in the vicinity. Again due to the delay sensitivity of multimedia traffic, and the nature of the IP backhaul, femtocell schedulers may have to compromise minimal ICI generation in order to meet end-to-end delay constraints. Additionally the high capacity nature of multimedia traffic will tend to increase ICI, unless appropriate techniques are used to limit this. Furthermore, the inherent uncertainty in the topology of the network in the presence of unorganized femto access points introduces extra dynamism to the nature of ICI in such networks. Therefore, to support QoS requirements, the resource allocation algorithms should have robustness against this impairment. Towards this objective, some basic characteristics of multimedia services can be combined with different topologies of femtocell networks to meet the demand while inflicting lower total interference on the network. Clusters of femtocells concentrated in different residential / enterprise buildings can provide the necessary platform to adopt such strategies. Here, the available traffic aggregator / gateway [4] within a block can act as the central controller to utilize local ICI coordination strategies like inter-cell power control, dynamic interference avoidance and frequency partitioning. Furthermore, multicasting can be employed to share similar resource blocks among adjacent femtocells with similar streaming demand. These approaches facilitate the migration towards fully decentralized strategies by introducing clustering and local controllers rather than a global entity and in turn lead to less total ICI and better service support in the network.

- **Self-Organisation and Optimisation.** Due to inevitable uncertainty about the scale of femtocell deployments and their dynamic presence creating new challenges, self-x operation is expected to play a key role in their success. Moreover, notice the fact that the current broadband multimedia data transmission has been realized mainly with the recent feasibility of the high-speed mobile internet within a single macrocell. Thus, the feasibility of new potential benefits from the self-x enabled femtocells may lead the evolution of various multimedia services highly demanded in a diverse environment. Specifically, for the multimedia transmission, it can be envisioned that the self-x algorithms for femtocells should be designed to have the following characteristics: minimal signalling overhead, agility to cope with acute dynamics of traffic and environment, full scalability to accommodate large number of nodes in the system and low complexity to enable cost effective practical implementation. Furthermore, in order to meet the high demands of bandwidth hungry multimedia applications, the self-x functions in femtocells need to operate at least on two different time scales with different but complementary objectives: 1) Short time scale with the objective of continuously maintaining optimal resource efficiency in the face of fast spatio temporal dynamics of traffic and environment e.g. by adapting power control, scheduling strategy, opportunistic reuse; 2) Large time scale with objective of focusing the resources where and when needed e.g. by antenna tilting, channel borrowing, load balancing, coverage pattern reshaping. Equipped with self-x features designed within the aforementioned vision, a variety of next generation multimedia services in diverse situations from indoors to outdoors and from fixed to highly mobile environments can become a reality.

**4. Opportunities and Challenges from Core Network's Perspective**

This section discusses the vision presented in section 2 from core network's perspective

- **Network Architecture**: To connect the femtocells back to the mobile network operator's (MNO) core network, available interfaces used in macrocells can be directly applied to minimize the requirement of equipment upgrading. However, the legacy functional entities originally designed for a limited set of high-traffic macro base stations may not function well for a large number of femtocells with bursty traffic. A femtocell gateway may be optionally deployed between the mobile core network and the broadband network to act as a concentrator [5]. Arising issues are the function splitting, scheduling and aggregation of multimedia traffic at the gateway. IP multimedia subsystem (IMS) provides a generic framework to offer VoIP and multimedia services for fixed-mobile convergence. The integration of IMS functionalities with femtocells needs further investigation [6].

- **Local Breakout**: One of the major benefits of deploying femtocells is brought by the capability of local breakout [7]. With this functionality, not only a direct connection can be created between a mobile handset and a device in the local network, but also the traffic can be exchanged with the Internet without traversing the mobile operator's network at the presence of a local gateway. In a home network, mobile users can exchange music and video with their home PC at a very high speed. In an enterprise network, extension calls and multimedia sharing can be locally enabled. For VoD and VoIP services originating from the Internet, direct IP access can significantly reduce the transmission latency compared to the conventional path via the mobile core network. To support local breakout, effective localized routing and placement of local gateways need to be studied. Other challenges include how to support simultaneous access to both the mobile core network via home routing and the Internet via local breakout, how to trigger local breakout from the MNO side and mobility issues. Other core network based functionality such as authentication, billing/accounting, end-to-end QoS and security may require a hybrid approach with some signalling traversing the core network, while user data is carried over local breakout.

- **Mobility**: Seamless mobility support is one of the key requirements of multimedia communications. The allowed latency for real-time applications is typically less than 150 ms. Whereas functional entities for mobility management may be located in the mobile core network (e.g. mobility management entity (MME) in 3GPP LTE/LTE-Advanced), femtocell access points are deployed on users' premises. They are connected via residential DSL or cable broadband, which may cost up to hundreds of milliseconds for end-to-end transmissions without additional prioritized mechanisms in the Internet. The immediate challenge arising for multimedia communications is how to maintain the service grade during handover from macrocell to femtocell, from femtocell to macrocell and between femtocells - re-routing multimedia streams in a disjoint core network, and keeping them synchronised between different cells is a challenge. For a networked femtocell scenario, local mobility management schemes need to be investigated to deploy functional entities locally such that the signalling does not need to reach the mobile core network. Additionally, there could be increased overheads on the radio access network, with more frequent handover signalling and procedures for mobile users. For a residential scenario, effective handover procedures need to be developed to minimize the impact of handover on the multimedia flows. Furthermore, handover for mobile femtocells is going to be quite challenging for multimedia users. Self-x procedures are expected to play a crucial role in addressing this issue.

- **Quality of Service (QoS)**: IP backhaul plays an important role in femtocell networks, especially for multimedia communications. Current IP backhaul network does not provide guarantees for delay-sensitive traffic. The situation may be even worse when the mobile operator and the broadband operator run independently. The challenges ahead are how to provide acceptable QoS over IP backhaul. The capability of IP backhaul supporting QoS also needs to be taken into account by mobility procedure. For instance, only cells with enough capabilities on their IP backhauls will be considered when the target cell is being selected. Admission control mechanisms need to be implemented at femtocells to maintain the required QoS level.

- **Security**: Effective mechanisms for authorization, authentication and accounting are essential requirements for multimedia communication. Different from binary data security, multimedia content is often of large volume and requires real-time response. Whereas femtocells use the same over-the-air security mechanisms that are used by macrocells, additional mechanisms are needed over the insecure IP backhaul to protect multimedia communication from growing security threats, e.g. denial of service attack and inspection of both signalling and media. Effective authentication mechanisms are also needed to avoid unauthorized access to femtocells and prevent "fake" femtocells collecting user and account details while minimizing their impact on the multimedia performance, e.g. handover latency. As the server for authentication and billing/accounting is normally located in mobile core network, the latency impact incurred by signalling over IP backhaul need to be mitigated.

## 5. Conclusions and Areas of Further Investigation

This paper has presented a vision in which next generation femtocells play a central role in provision of advanced multimedia services in a variety of daily life scenarios covering the indoor home environment, and outdoor mobile environment, as well as new and unprecedented multimedia support for emergency and safety services. Key issues and challenges from both radio access as well as core network's perspective have also been identified, that need further investigation in order to fully realise the presented vision. In particular, high latency has been pointed as a key issue not only from scheduling perspective but also from seamless mobility point of view. It is conjectured that self-x operation is expected to play a key role in addressing some of the challenges by smart and intelligent optimisation of radio parameters. Among other issues that could be further studied is to compare femtocells versus broadcast / point-to-region multicast in macrocells for delivery of multimedia, although this comparison will also depend on the service delivery models (e.g. femtocells work better for real "on-demand" delivery, whereas broadcast might work better for scheduled transmissions, with intelligent pre-caching at the receiver).

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