Energy Efficiency Evaluation of SISO and MIMO between LTE-femtocells and 802.11n Networks

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***Abstract*—The objective of this paper is to provide the methodology and results that is used to evaluate a scalable energy performance comparison of LTE-femtocells and 802.11n with both SISO and MIMO antenna configurations. The performance is derived in a multi-user and multi-cell wireless communication system. A system level LTE-femtocell simulator has been developed and an analytical model to evaluate 802.11n network performances has been proposed. It is shown that 1 Femtocell Access Point consistently perform better than 1 802.11n Access Point. This may be explained by the centralised resource allocation and channel access methods used by femtocells compared to distributed methods and CSMA/CA used by 802.11 networks. Generally, SISO deployment is more energy efficient than Alamouti MIMO 2 × 2.**

I. Introduction

In recent years, mobile data traffic has experienced a growth due to the increased popularity of smartphones. Demand for higher data rates has created new challenges for cellular operators. This is especially the case for indoor mobile users. Femtocells and 802.11n Wi-Fi networks have been deployed to indoor locations where there is no sufficient outdoor cellular coverage. Femtocells have attracted significant attention as a solution to increase the system capacity [1]. Femtocell Access Points (FAPs) like Wi-Fi Access Points (APs) are likely to be randomly deployed and to be moved by users easily. With the introduction of femtocell technology, serving indoor users with large service demand are becoming cheaper compared with those served by outdoor micro-cells and is also very similar to Wi-Fi technology in terms of architecture, operating frequency, offered services and data rates [2].

A. Review

Femtocells still face many technical as well as business challenges compared with Wi-Fi technology despite their potentials. The co-channel deployment of a femtocell layer will impact the existing micro-cell networks, affecting their capacity and performance [3]. Another serious problem for femtocell deployment is the incidence of unnecessary handover due to movement of the user. These unnecessary handovers cause the reduction of user's Quality of Service (QoS) level and system capacity [4]. From the service provider point of view a major concern is the energy efficiency of femtocell technology, which is vital for the practical deployment of femtocell and competition with widely deployed 802.11 networks. Existing work on 802.11 Medium Access Control (MAC) layer [5], [6] employ models that assume an ideal wireless channel with no physical layer channel errors. In fact, wireless channels are usually error-prone and the effects of packet errors have an impact on the system performance. In this paper, an approach has been introduced to study the saturated throughput, user QoS and energy consumption performances of 802.11n networks under error-prone channels by extending Bianchis model. Two ways to perform frame aggregation at the MAC layer are specified in 802.11n standard, which has also been considered in this model. [7].

B. Research Contribution

This paper aims to investigate the energy efficiency of femtocell and 802.11 networks in both conventional and alternative scenarios by designing a fair and scalable performance comparison framework and performing extensive comparisons based on the framework. In the baseline conventional scenario, 802.11n APs are deployed on three non-overlapping channels using a total bandwidth of 60 MHz while FAPs are assumed to operate on the same frequency with a total bandwidth of 20 MHz. In the alternative scenario, both 802.11n APs and FAPs have a total bandwidth of 20 MHz with a frequency reuse pattern 1 and 3, respectively.

A system level simulator to evaluate a multi-cell multi-user with SISO and MIMO antenna configurations LTE-femtocells network is implemented, and an analytical model to evaluate 802.11n network performance is also developed.

This paper is organised as follows. Section II describes the body of investigation and a baseline system LTE-femtocell simulator is also introduced. Section III proposes the 802.11n analytical model. The energy metrics are illustrated and derived in Section IV. The simulation results comparing the performance of the two technologies are presented in Section V. Finally, Section VI concludes the paper.

II. LTE-femtocells Simulator Model

A. Simulation Flow

The propagation channel between each user and FAP is calculated and Round Robin (RR) scheduling is performed for each snapshot. The path loss model is adopted from [8]. Resource allocation is performed at intervals of 1 ms called a transmission time interval (TTI). A total number of 50 users are distributed randomly and uniformly across the whole enterprise office whose area is 20 m × 16 m. This study

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considers one single floor building without light internal walls. The number of FAPs varies from 1 to 6. Link adaptation was implemented by changing the Modulation and Coding Scheme (MCS) based on the Signal to Interference-plus-Noise Ratio (SINR). The MSC look-up tables were generated from the Vienna link level LTE simulator [9] under WINNER II A1 multipath model [10].

As each FAP's antenna is omni-directional, there is always one FAP deployed in the middle of the office except for the case of 2 FAPs, in which case they are placed at the foci of the ellipse layout. For the remaining deployments, all other APs excluding the middle one are placed evenly around the circumference of the ellipse as shown in Fig. 1. In this paper, the **user QoS** is definded as the 95%-ile threshold of user data rate, thus if the **user QoS** target is set to 2 Mbit/s then at least 95% of users achieve a minimum data rate of 2 Mbit/s.

B. Signal Model and System Level SINR Calculation

1) SISO: The baseband downlink received signal in the presence of the interference can be expressed as follows:

$$y_0[t] = h_0 x_0[t] + \sum_{k=1}^{K} h_k x_k[t] + w_0[t], \quad (1)$$

where h_0, $h_k \sim \mathcal{CN}(0,\, 1)$ and $w_0 \sim \mathcal{CN}(0,\, \sigma^2)$ are the multi-path coefficient of the desired base station, k^{th} interfering base station and the noise at time t, respectively. They are modelled as independent and identically distributed (i.i.d.) circularly symmetric complex Gaussian random variables with zero mean and a variance of one and σ^2 at time t. The output estimated signal from the matched filter is given by Eq. (2) (projecting the received signal in the direction of the channel):

$$\hat{y}_0[t] = \frac{h_0^* y_0[t]}{|h_0|^2} = x_0[t] + \frac{h_0^*}{|h_0|^2}\sum_{k=1}^{K} h_k x_k[t] + \frac{h_0^*}{|h_0|^2} w_0[t]. \quad (2)$$

The SINR of the estimated signal γ_{SISO} can be calculated as below:

$$\begin{aligned}\gamma_{\text{SISO}} &= \frac{\mathbb{E}\left(|x_0[t]|^2\right)}{\mathbb{E}\left(|\frac{h_0^*}{|h_0|^2}\sum_{k=1}^{K} h_k x_k[t]|^2\right) + \mathbb{E}\left(|\frac{h_0^*}{|h_0|^2} w_0[t]|^2\right)},\\ &= \frac{P_0}{\frac{1}{|h_0|^2}\sum_{k=1}^{K}|h_k|^2 P_k + \frac{1}{|h_0|^2}\sigma^2} = \frac{|h_0|^2 P_0}{\sum_{k=1}^{K}|h_k|^2 P_k + \sigma^2},\end{aligned} \quad (3)$$

where P_0 is the received power of a certain sub-carrier from the desired base station, P_k is the received power of the same sub-carrier from the k^{th} interfering base station and σ^2 is the noise power.

2) MIMO Alamouti 2 × 2: The downlink channel with Alamouti 2 × 2 received signal model can be expressed as:

$$\mathbf{y}_{0\_22}[t] = \mathbf{H}_{0\_22}\mathbf{x}_{0\_22}[t] + \sum_{k=1}^{K}\mathbf{H}_{k\_22}\mathbf{x}_{k\_22}[t] + \mathbf{w}_{0\_22}[t], \quad (4)$$

where $\mathbf{x}_{0\_22}$ and $\mathbf{x}_{k\_22}$ are the transmit vectors (2 × 1), $\mathbf{w}_{0\_22}$ is a noise vector (2 × 1) and its samples are circularly symmetric complex Gaussian distribution variables $\sim \mathcal{CN}(0,\, \sigma^2)$ with zero mean and variance of σ^2. $\mathbf{H}_{i\_22}(i = 0, k)$ is an equivalent channel matrix given by:

$$\mathbf{H}_{i\_22} = (\mathbf{H}_{1i\_22}, \mathbf{H}_{2i\_22})^T, (i = 0, k), \quad (5)$$

where $\mathbf{H}_{1i\_22} = \begin{pmatrix} h_{1i1} & h_{1i2} \\ h_{1i2}^* & -h_{1i1}^* \end{pmatrix}$ and $\mathbf{H}_{2i\_22} = \begin{pmatrix} h_{2i1} & h_{2i2} \\ h_{2i2}^* & -h_{2i1}^* \end{pmatrix}$ are the equivalent Alamouti matrices of received antenna 1 and antenna 2, respectively. h_{1i1}, h_{1i2}, h_{2i1} and h_{2i2} are the multi-path coefficients modelled as i.i.d circularly symmetric complex normal random variables $\sim \mathcal{CN}(0,\, 1)$ with zero mean and a variance of one. h_{1i1} and h_{1i2} are from transmit antenna 1 and 2 to receive antenna 1, while h_{2i1} and h_{2i2} are from transmit antenna 1 and 2 to receive antenna 2 of the i^{th} base station. Therefore, Eq. (5) can be re-written as: $\mathbf{H}_{i\_22} = \begin{pmatrix} \mathbf{H}_{1i\_22} \\ \mathbf{H}_{2i\_22} \end{pmatrix}, (i = 0, k)$. The estimated signal from the Alamouti receiver can be obtained by multiplying $\mathbf{y}_{0\_22}[t]$ with the pseudo inverse of the equivalent channel matrix of the corresponding base station. For a general (non-square) matrix, the pseudo inverse is defined as $\mathbf{H}^{-1} = (\mathbf{H}^H\mathbf{H})^{-1}\mathbf{H}^H$, where $\mathbf{H}^H$ is the transpose conjugate of the matrix $\mathbf{H}$. Hence the estimated signal $\hat{\mathbf{y}}_{\mathbf{0\_22}}[t]$ is given by:

$$\begin{aligned}\hat{\mathbf{y}}_{\mathbf{0\_22}}[t] &= (\mathbf{H}_{0\_22}^H\mathbf{H}_{0\_22})^{-1}\mathbf{H}_{0\_22}^H\mathbf{y}_{0\_22}[t],\\ &= (\mathbf{H}_{0\_22}^H\mathbf{H}_{0\_22})^{-1}\mathbf{H}_{0\_22}^H\mathbf{H}_{0\_22}\mathbf{x}_{0\_22}[t]\\ &+ \sum_{k=1}^{K}(\mathbf{H}_{0\_22}^H\mathbf{H}_{0\_22})^{-1}\mathbf{H}_{0\_22}^H\mathbf{H}_{k\_22}\mathbf{x}_{k\_22}[t]\\ &+ (\mathbf{H}_{0\_22}^H\mathbf{H}_{0\_22})^{-1}\mathbf{H}_{0\_22}^H\mathbf{w}_{0\_22}[t],\end{aligned} \quad (6)$$

where $\mathbf{H}_{i\_22}^H\mathbf{H}_{i\_22}$ and $(\mathbf{H}_{i\_22}^H\mathbf{H}_{i\_22})^{-1}\mathbf{H}_{i\_22}^H\mathbf{H}_{i\_22}$ can be calculated by the following Eq. (7) and Eq. (8):

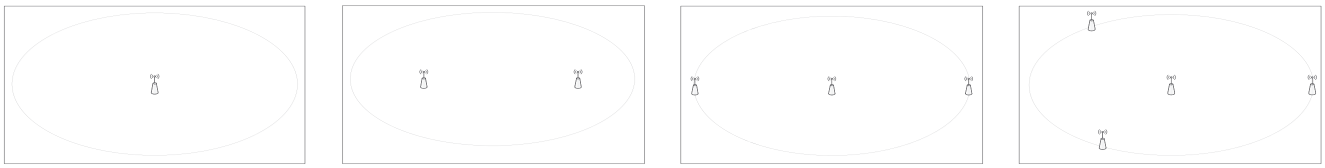
$$\mathbf{H}_{i\_22}^H\mathbf{H}_{i\_22} = \frac{\|\mathbf{H}_{i\_22}\|^2}{2}\mathbf{I}_2, (i = 0, k), \quad (7)$$

$$(\mathbf{H}_{i\_22}^H\mathbf{H}_{i\_22})^{-1}\mathbf{H}_{i\_22}^H\mathbf{H}_{i\_22} = \mathbf{I}_2. \quad (8)$$

where $\mathbf{I}_2$ is a 2 × 2 identity matrix and $\|.\|$ is an operation of Frobenius norm for a vector or matrix (e.g. $\|\mathbf{H}_{i\_22}\| = \sqrt{2(|h_{1i1}|^2 + |h_{1i2}|^2 + |h_{2i1}|^2 + |h_{2i2}|^2)}$). Eq. (6) can be simplified as:

$$\begin{aligned}\hat{\mathbf{y}}_{\mathbf{0\_22}}[t] &= \mathbf{I}_2\mathbf{x}_{0\_22}[t] + \frac{2}{\|\mathbf{H}_{0\_22}\|^2}\\ &\times\left(\sum_{k=1}^{K}\mathbf{H}_{0\_22}^H\mathbf{H}_{k\_22}\mathbf{x}_{k\_22}[t] + \mathbf{H}_{0\_22}^H\mathbf{w}_{0\_22}[t]\right),\end{aligned} \quad (9)$$

The SINR of the estimated signal $\gamma_{\text{MIMO}2\times2}$ can be calculated from Eq. (10) (Note that the transmit power is shared between two antennas in order to have the same total radiated power from two transmit antennas and hence the received power is



(a) 1 FAP (b) 2 FAPs (c) 3 FAPs (d) 4 FAPs

Fig. 1. Femtocell access point placement for 1, 2, 3 and 4

$$\gamma_{\text{MIMO2}\times 2} = \frac{\frac{1}{2}P_0\mathbf{I}_2}{\frac{4}{\|\mathbf{H}_{0\_22}\|^4}\left[\sum_{k=1}^{K}\mathbb{E}(\mathbf{H}_{0\_22}^H\mathbf{H}_{k\_22}\mathbf{H}_{k\_22}^H\mathbf{H}_{0\_22})\frac{1}{2}P_k + \mathbb{E}(\mathbf{H}_{0\_22}^H\mathbf{H}_{0\_22})\sigma^2\right]} = \frac{\|\mathbf{H}_{0\_22}\|^4P_0\mathbf{I}_2}{4\sum_{k=1}^{K}H_{22}P_k\mathbf{I}_2 + \|\mathbf{H}_{0\_22}\|^2\sigma^2\mathbf{I}_2}. \tag{10}$$

also halved). Where $\mathbb{E}(\mathbf{H}_{0\_22}^H\mathbf{H}_{k\_22}\mathbf{H}_{k\_22}^H\mathbf{H}_{0\_22}) = H_{22}\mathbf{I}_2$, $H_{22} = (|h_{101}|^2 + |h_{102}|^2)(|h_{1k1}|^2 + |h_{1k2}|^2) + (|h_{201}|^2 + |h_{202}|^2)(|h_{2k1}|^2 + |h_{2k2}|^2)$. Eq. (10) implies that the SINR values on both antenna streams are identical and the symbols can be decoupled at the receiver easily owing to the characteristic of Alamouti scheme. Hence, the SINR value for Alamouti 2 × 2 is equal to:

$$\gamma_{\text{MIMO2}\times 2} = \frac{\|\mathbf{H}_{0\_22}\|^4P_0}{4\sum_{k=1}^{K}H_{22}P_k + \|\mathbf{H}_{0\_22}\|^2\sigma^2}. \tag{11}$$

III. 802.11n Analytical Model for Energy Efficiency Evaluation

Bianchis model was selected and extended to propose an energy analytical model for 802.11n, and several assumptions have been made. The model is concerned with infrastructure mode Wireless Local Area Networks (WLANs) that use the Distributed Coordination Function (DCF) MAC protocol. Therefore, DCF is used for single-hop only communication within the cells and users access data through their serving APs. Each user is assumed to have saturated traffic. The wireless channel Bit Error Rate (BER) is P_b. The minimum contention window size is W and the maximum backoff stage is m. The system time is divided into small time slots where each slot is the time interval between two consecutive countdowns of backoff timers by stations which are not transmitting. From Bianchis model, transmission probability τ in a virtual time slot is given by:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1)+pW(1-2p)^m}, \tag{12}$$

where p is the unsuccessful transmission probability conditioned on that there is a transmission in a time slot. When considering both collisions and errors, p can be expressed as:

$$p = 1-(1-p_c)(1-p_e), \tag{13}$$

where $p_c = 1-(1-\tau)^{s-1}$ is the packet conditional collision probability and $p_e = 1-(1-p_b)^L$ is the packet error probability on condition that there is a successful transmission in the time slot. s is the total number of contending stations. L is the packet size in bits and p_b is the BER of a particular MCS level. Therefore, the network saturation throughput can be calculated as: $S = \frac{E_p}{E_t}$, where E_p is the average packet payload bits successfully transmitted in a virtual time slot, and E_t is the expected length of a time slot. E_p and E_t are computed by $E_p = Lp_s = Lp_{tr}p_{s\_nc}(1-p_e)$ and $E_t = T_\sigma p_\sigma + T_c p_{tr}(1-p_{s\_nc}) + T_e p_e + T_s p_s$, where the probability of an idle slot p_σ is $(1-\tau)^s$, the probability of a non-collided transmission p_{s_nc} is $\frac{s(1-\tau)^{s-1}}{p_{tr}}$, the probability for a transmission in a time slot p_{tr} is $1-p_\sigma = 1-(1-\tau)^s$, the probability of a successful transmission (without collisions and transmission errors) is $p_{tr}p_{s\_nc}(1-p_e)$ and τ is computed by (12). T_σ is equal to the systems empty slot time of 9 μs. T_σ, T_c T_s and T_e are the idle, collision, successful and error virtual time slots length and are defined as follows: T_σ is equal to the system's empty slot time of 9 μs, T_c = EIFS, T_s = DATA + BACK + 3SIFS + DIFS, T_e = DATA + EIFS + 2SIFS, where BACK = 5.63 μs and DATA are the transmission time for backoff stage and the transmission time for aggregated data frame, SIFS = 16 μs, DIFS = SIFS $+T_\sigma$, EIFS = SIFS + DIFS + BACK, respectively.48 of the 52 OFDM sub-carriers are for data and the remaining 4 are for pilot sub-carriers. Each of these sub-carriers can be a BPSK, QPSK, 16QAM or 64QAM.

IV. Energy Metrics

The power consumption model employed by this paper considers the FAP and 802.11n APs to have the same model. The model considers the power consumption of an AP to have two distinct parts: a radio-head (RH) and an overhead (OH). Together the RH and OH constitute the operational (OP) power consumption. During transmission, the RH is active, and irrespective of transmission, the OH is always active.

In order to compare the energy consumption of the same system operating in different conditions, the concept of transmission and operational duration are defined. Consider an AP with indoor users that demand a traffic load of M bits of data over a finite time duration of $T_{\text{AP}}^{\text{OH}}$. Two systems are considered: a reference and a test system, both of which have a capacity that exceed the offered traffic load. Due to the fact that the reference and the test system might have different throughput, the duration which the RH spends in transmitting the same M bits is different. In order to compare the energy of the two systems, a useful metric is the **Energy Reduction Gain (ERG)**, which is the reduction in energy consumption when a test system is compared with a reference system:

$$\mathrm{ERG}_{\mathrm{RAN}}^{\mathrm{OP}} = 1 - \frac{E_{\mathrm{AP,test}}^{\mathrm{OP}}}{E_{\mathrm{AP,ref.}}^{\mathrm{OP}}} = 1 - \frac{nP_{\mathrm{test}}^{\mathrm{RH}} \frac{R_{\mathrm{traffic}}}{R_{\mathrm{AP,test}}} + nP_{\mathrm{test}}^{\mathrm{OH}}}{nP_{\mathrm{ref.}}^{\mathrm{RH}} \frac{R_{\mathrm{traffic}}}{R_{\mathrm{AP,ref.}}} + nP_{\mathrm{ref.}}^{\mathrm{OH}}}, \quad (14)$$

where P_i^{RF}, P_i^{RH} and P_i^{OH} are RF power, RH power and OH power, respectively. The RH power is defined as $P_i^{\mathrm{RF}}/\mu_\Sigma = P_i^{\mathrm{RH}}$, where μ_Σ is the RH efficiency [11]. The throughput of the system is defined as $R_{\mathrm{AP},i} = M/T_{\mathrm{AP}}^{\mathrm{RH},i}$, which is greater or equal to the offered load: $R_{\mathrm{traffic}} = M/T_{\mathrm{AP}}^{\mathrm{OH}}$. The term $\frac{P_i^{\mathrm{RH}}}{R_{\mathrm{AP},i}}$ in (14) is an indication of the average radio transmission efficiency, which does not consider the overhead energy. This is commonly used to measure energy consumption in literature, and is known as the **Energy-Consumption-Ratio (ECR)**. n refers to the total number of APs.

V. Network Simulations and Results

A. Baseline Results without Outdoor Interference

In this section, simulation results obtained from conventional scenario with the co-channel FAPs are presented. Fig. 2 illustrates the **user QoS** and average user data rate versus different number of indoor base stations for both LTE-femtocells and 802.11n network with SISO and MIMO antenna configurations.

1) 1 Access Point: It is shown that 1 FAP can achieve the highest **user QoS** of just over 1 Mbit/s in both SISO and MIMO deployment owing to the absence of any interference. Fig. 3(a) shows 43% improvement in the spectral efficiency when using 1 FAP as compared to 1 AP. This can be obtained from Fig. 3(a). This gain is due to the different scheduler mechanism between LTE-femtocell and 802.11n network. Fig. 4(a) shows that 1 FAP offers 4.44% and 0.40% ERG against 1 baseline 802.11n AP with SISO and MIMO deployment, respectively.

2) 2 or More Access Points: The **user QoS** of 2 FAPs is less than that of 1 FAP. However for the number of FAPs greater than 2, the **user QoS** steadily increases with the number of FAPs. On the other hand, for the number of APs is less than or equal to 3, **user QoS** of 802.11n network has a linear growth due to the utilisation of the entire 60 MHz bandwidth and acquires the highest **user QoS** in the scenario of using 3 APs shown in Fig. 3(b). after which the **user QoS** starts decreasing due to inter-AP interference. Comparing Fig. 2(a) and Fig. 2(b), the average user data rate trend is roughly same as the **user QoS** trend but the **user QoS** data rate is lower. For the number of APs greater than 2, 802.11 APs provides 2.61% to 16.72% ERG over FAP for utilising more bandwidth than FAP as shown in Fig. 4(a).

3) SISO vs. MIMO: Fig. 3(c) and Fig. 3(d) show that Alamouti MIMO 2 × 2 provides benefit in spectral efficiency relative to conventional SISO for both LTE-FAPs and 802.11 APs. However, MIMO is less energy efficient than SISO because MIMO consumes double OH power compared to SISO [11]. Fig. 4(b) shows that SISO yields an ERG of roughly 40% and 45% for FAP and 802.11n, respectively. This suggests that the overhead power dominates the energy performance for this study. Therefore, there is a possibility for MIMO to outperform SISO in the energy perspective. For example, if the **user QoS** of FAP is set around 0.5 Mbit/s, it can be observed in Fig. 2(a), 2 MIMO FAPs is sufficient to meet this requirement while more than 6 SISO FAPs is needed assuming the trend of **user QoS** remains steadily increasing after the number of FAP is 6.

B. Results with Outdoor Interference

There is an interest to explore how the interference from outdoor micro-cell base station will affect the performance of indoor co-channel deployed FAPs. This micro-cell is placed 150–200 m away from the office with 20 watts transmitting power. The interference is calculated on a sub-carrier level with WINNER II B4 multipath model considered [10]. The **user QoS** in 1 FAP deployment drops by 0.25 Mbit/s and the average data rate decreases by 0.08 Mbit/s compared to micro-cell interference-free scenario of Fig. 3(a). However 1 AP still cannot outperform 1 FAP even with the outdoor interference.

C. Frequency Reuse Scenario

The alternative scenario is defined in Section II, in which both FAPs and 802.11n APs have a total bandwidth of 20 MHz with a frequency reuse pattern 3 and 1, respectively. Fig. 4(c) and Fig. 4(d) show the **user QoS**, average data rate and ERG performance for conventional and alternative scenario with a baseline 802.11n network. The case of 1 FAP and 1 802.11n AP for both conventional and alternative scenarios are identical. Fig. 4(d) indicates FAP provides an ERG of 17.90% in alternative scenario while 802.11n AP offers an ERG of 16.72% in conventional scenario.

VI. Conclusions

The results of this paper indicate that one LTE-Femtocell (FAP) is always more energy efficient than one 802.11n AP. 802.11n AP achieves the highest **user QoS** and average user data rate when fully utilising its 60 MHz bandwidth with frequency reuse pattern 3 whereas FAP suffers severe co-channel interfering effects and the **user QoS** drops dramatically when the number of FAP is greater than 1 in conventional scenario. For the number of APs greater than 2, 802.11n APs provides an ERG of 2.61% to 16.72% over FAP. It is also illustrated that FAPs are always more energy efficient than 802.11n in the alternative scenario. The Alamouti MIMO 2 × 2 scheme yields higher spectral efficiency but at the cost of consuming twice the overhead power which results into a less energy efficient performance.

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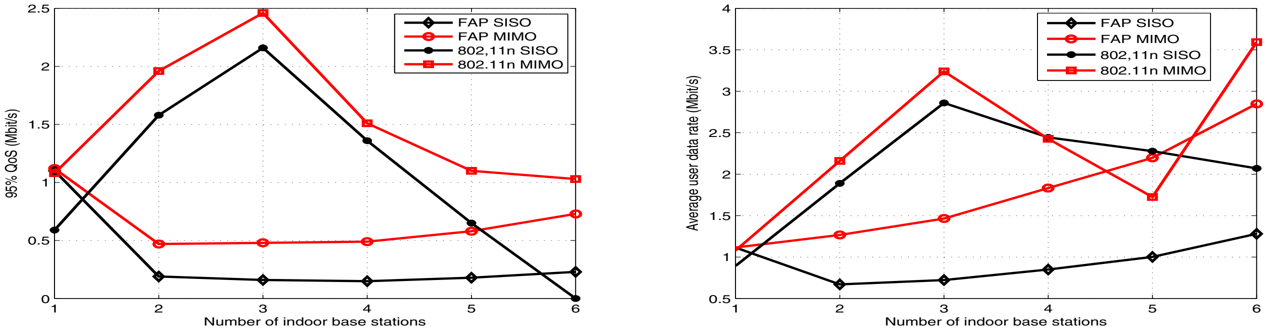
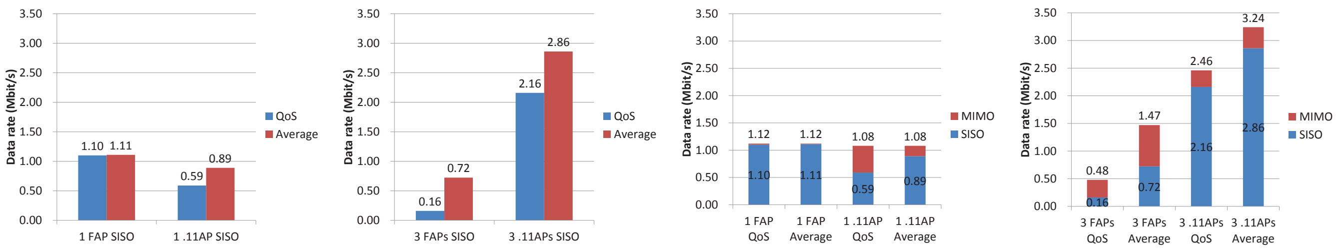


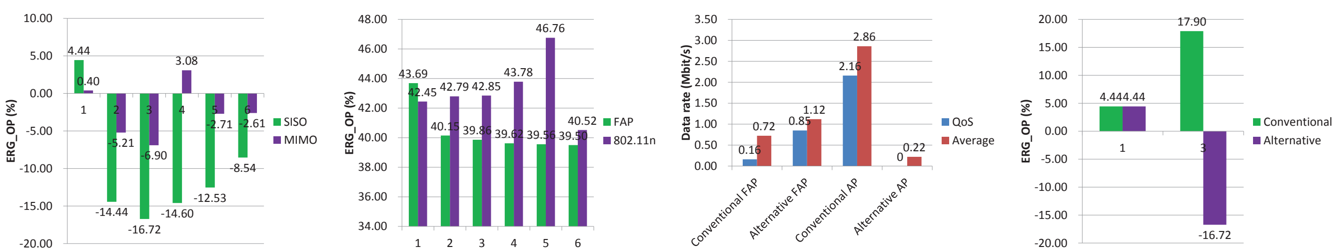
(a) User QoS (b) Average user data rate

Fig. 2. QoS and average user data rate vs. the number of indoor APs for FAPs and 802.11n with SISO and MIMO deployment without outdoor interference



(a) 1 FAP vs. 1 .11AP SISO (b) 3 FAPs vs. 3 .11APs SISO (c) 1 FAP vs. 1 .11AP SISO (d) 3 FAPs vs. 3 .11APs SISO

Fig. 3. User QoS and average user data rate comparison between LTE-femtocells and 802.11n with SISO deployment without outdoor interference



(a) FAP vs. baseline 802.11n AP (b) SISO vs. baseline MIMO (c) User QoS and average user data rate (d) ERG comparison

Fig. 4. ERG comparison for LTE-femtocells and 802.11n with SISO and MIMO deployment without outdoor interference, and User data rate and ERG comparison vs. 3 FAPs and 3 APs SISO deployment between conventional and alternative scenarios

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