Economical Comparison of Enterprise In-building Wireless Solutions using DAS and Femto

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Abstract—**As small cell solutions for efficient in-building wireless deployment, the distributed antenna system (DAS) and Femtocells constitute two major options. In this work, we study the Total Cost of Ownership (TCO) in combination with system performance in order to reach technology-economical conclusions regarding of these deployment options. Our aim is to identify the most cost economical solution for indoor wireless deployment which meets the indoor capacity need and provides ubiquitous indoor coverage. In the analysis we focus on LTE enhancement in the enterprise buildings. We discuss the unique cost features of DAS and Femto systems and highlight the importance of backhaul visibility in the cost analysis. For enterprise building solutions, we show the cost advantage of low-cost Femtocells over DAS in all scenarios regardless of coverage building size. We also suggest when DAS becomes more economical for large buildings with low data traffic need.**

Keywords- in-building wireless system, cost analysis, backhaul, Femto, distributed antenna system

I. INTRODUCTION

The rapid growth of mobile data traffic, along with the fact that the majority traffic is generated in-building [1], has stressed mobile operators to carefully consider their deployment strategy for in-building capacity and coverage. In-building wireless system deployment covers a vast variety of installation options. In this paper we focus on the cost analysis of distributed antenna system and the Femtocells as two of the major indoor options.

The DAS concept was developed decades ago [2]. DAS is composed of many remote antenna ports distributed over a large area and connected to a single Base Station (BS) by fiber, coax cable or microwave links [3]. The same downlink signal is broadcasted by the BS on all its antennas, which improves the signal quality over the entire coverage area. On the other hand, Femto is an alternative way to extend the indoor coverage and capacity where multiple access points are deployed to achieve both coverage and capacity. While Femtocells are commonly discussed for residential usage on digital subscriber line (DSL) or cable broadband, they exist in enterprise/hotspot capable variants as well as with boosted capacity, such as higher Radio Frequency (RF) power and higher number of supported users.

Though research and discussions regarding the indoor applications of DAS and Femto have been active for years, most mobile operators still hold a quite open view when it comes to a wide-spread deployment of in-building systems for data offloading in their next generation networks with LTE. The essential considerations are performance and cost. The performance of DAS and Femto was studied in existing literature, for example in [4], in [5][6] and [7] respectively. In general, from the capacity perspective, Femto is seen as a more scalable solution with the potential of serving high capacity with dense deployment. Regarding mobility performance, Femto relies on effective cell selection mechanisms, which requires more careful planning and optimization; meanwhile, the mobility performance of DAS is high. DAS has also some inherent advantages in terms of operability and maintenance allowing the digital and RF components to be located in a convenient location. In this paper, we focus on the other critical factor that affects in-building wireless solution: cost. Some other studies can be found on similar topics, for example in [8], where the authors suggest great potential for residential Femto deployment. However, their work focuses on the mobile operators' massive network rollout of indoor small cells and analyzes the cost savings compared to macro-only upgrade. The TCO analysis in this paper compares the dedicated indoor system: passive DAS and Femto, aiming at a better understanding of the future cost-efficient indoor solutions. The analysis is conducted in the LTE enhancement context, that only the cost related to LTE system is considered. Cost figures from different regions (developed/developing countries) are covered in this study where distinctive market characteristics can make a difference on the comparison of variant in-building systems. We consider the single operator, single radio access technology and single spectrum band case for the benchmark.

The paper is organized as follows. In section II, we introduce the two indoor systems, passive DAS and the Femto system. We also demonstrate the site-specific office building model used for system design and performance evaluation. In section III, the cost model and methodology used in TCO analysis is described. The main findings and results are presented in section IV. The conclusion is drawn in section V.

II. INDOOR SYSTEM DESIGN

A. DAS

DAS is composed of many remote antenna ports distributed over a large area which are connected to a single BS by fiber, coaxial cable or other types of cables. The passive DAS usually uses coaxial cable as the feeder of the remote antennas. Without advanced signal processing at the central base station, the same downlink signal is broadcasted on all its antennas. Due to the fact that the distributed system of DAS is composed of variant types of passive devices, the construction of DAS involves massive components. Expensive installation works are usually expected for passive DAS for laying the heavy coaxial cables throughout the building.

In the era of LTE, the mobile operators are willing to build the system with the multiple-input-multiple-output (MIMO) technique to facilitate higher peak data rate. However, for DAS this requires installing a parallel distributed system[1], because each transmitter port needs its own independent feeder line to the base station. For practical reasons, normally only up to 2 transmit antennas at base station are assumed for indoor LTE system. Two transmitting antennas in the downlink direction means that a pair of passive feeders are to be installed. This raises the cost and adds installation complexity to the system.

Normally, a medium sized building can be covered by a single cell DAS. Further capacity can be inserted by splitting the DAS cell into multiple sectors. By dividing the whole building into smaller areas, the radio signal from different LTE sectors can be distributed to separate coverage areas. This increase the special reuse of radio resources, but it also raises intra-site interference.

B. Femto

Femtos are portable, low cost and low range BSs designated for indoor usage, where they are connected to the operator network by residential digital subscriber line (DSL) or cable broadband. The plug-and-play nature eases the installation of Femto systems. There are also fewer devices involved in Femto deployment comparing to the DAS.

C. Office building model

A three-floor office building model is used in designing the site-specific in-building systems and in evaluating their radio performance. The floor plan shown in Figure 1 and the propagation model follow the WINNER II office model [9].

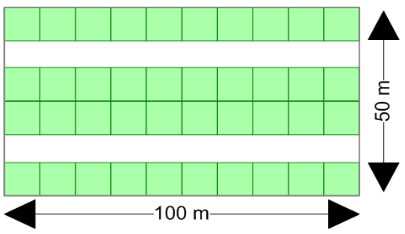

Figure 1. Site-specific building floor plan

III. TCO MODELING AND METHODOLOGY

The Total Cost of Ownership is a financial estimate to determine the direct and indirect costs of a product or a system over a certain time period, which is composed of capital expenditure (CAPEX), implementation expenditure (IMPEX) and operational expenditure (OPEX).

$$TCO = C_{CAPEX} + C_{IMPEX} + C_{OPEX} \tag{1}$$

Either DAS or Femto has its unique cost feature. The concepts of CAPEX, IMPEX and OPEX and their composition for different indoor wireless systems are presented in this section, followed by a brief introduction of the discrete present value method used in the TCO analysis. A summary of detailed cost elements of DAS and Femto can be found in TABLE I. .

A. CAPEX

CAPEX, by definition, is incurred when a business spends money either on buying fixed assets or on adding to the value of an existing fixed asset with a useful life extended beyond the taxable year. CAPEX is spent on assets that can be disassembled and relocated. In the context of mobile operators, CAPEX represents the initial equipment and software investments that are related to deploying and upgrading the mobile networks.

Based on current market price, the capital expenditure of a three-sector 2-by-2 MIMO LTE base station including both hardware and software license, is assumed at 20,000 €; a Pico base station is worthy around 3,100 €.

The Femto-related cost figures are listed below:

- Low-cost Enterprise Femto access point (FAP): 250 €
- High-cost Enterprise FAP: 800 €
  - Depreciation period of FAP: 2.5 years
- Femto gateway: 20 €
  - Depreciation period of Femto gateway: 5 years

B. IMPEX

IMPEX is the capital expenditure that would have to be repeated if the cellular site is moved. In most cases, the costs are associated with planning and installing the system. The installation cost of a Femto access point is assumed at 250 €; and the designing and planning cost for Femto system is accordingly assumed of 400 € per Femto. For DAS, the installation cost is the summation of installation cost of all DAS components.

C. OPEX

OPEX is the on-going cost for running a product, business, or system. In the context of mobile operators, OPEX is related to operation and maintenance of networks and service provisioning. Except for backhaul related OPEX, the remaining part can be estimated as a fixed portion of the total CAPEX. In mobile networks, the yearly OPEX is often estimated as 5% to 10% of CAPEX. The higher bound of 10% is used in this study. For Femto systems, it is estimated that the annual OPEX amounts to 20% of CAPEX.

D. Discrete Present Value

The discrete present value (DPV) analysis is an important tool in our TCO analysis for evaluating the outgoing cash flow of the project. In DPV analysis, all discrete future cash flows are estimated and discounted to give their present values. DPV is defined by the following expression:

$$DPV = \sum_{t=0}^{N} \frac{VF_t}{(1+r)^t} \tag{2}$$

Where VF_t stands for the future value at the beginning of the *(t+1)'th* period (t=0 means that VF_0 is the present value by itself); N is the total number of periods, and r stands for the interest rate. In the following analysis, unless otherwise stated, the time period is counted in units of years, and the total TCO is calculated for a 5-year period, including the discounted 5 years' OPEX.

TABLE I. SUMMATION OF TCO COMPONENTS

	DAS	**Femto**
CAPEX	Base station Distributed System: – Remote antennas, wideband combiner, power splitter, coupler, coaxial cable, cable connecter, etc. Backhaul equipment Software cost Supporting equipment – Wall mounting kit, power cable, battery backup, alarm system, etc.	Base station (antenna/front-haul integrated, software license included in price)
IMPEX	(Site acquisition and	System planning and

[1] The distributed system of a DAS is defined as from the output port of the radio frequency module of the base station to the air interface of the remote antennas.

	construction) System planning and initial optimization Installation of base stations Installation of distributed system Coordination cost due to disruptive DAS construction work	initial optimization Installation of base stations
OPEX	Backhaul operations and maintenance Backhaul rent (Site rent) Power consumption Offsite support Site visit for trouble shooting or maintenance	Backhaul operations and maintenance Backhaul rent Power consumption Offsite support Site visit for trouble shooting or maintenance

IV. TCO COMPARISON OF INDOOR SYSTEMS

In this section we demonstrate the main findings of the TCO analysis comparing the indoor passive DAS and the Femto systems. To make a clear view on how backhaul cost is impacting the overall picture of TCO comparison, we make separate studies on the TCO with and without backhaul cost.

The radio performance results used in the following text are derived from system simulation with the building model illustrated in Figure 1. To provide adequate coverage in the site-specific building model, a total of 12 Femtocells are used for the Femto system. A DAS is designed for the same building with 8 distributed antennas per floor. The building is assumed to be located in a macro coverage hole. In the simulation, an LTE system of 8MHz downlink bandwidth in the 2.3GHz band is assumed. The system performance is simulated by assuming Poisson traffic model with a fixed user buffer size of 2Mb. Optimal switching between transmit diversity and spatial multiplexing is assumed for 2-by-2 MIMO system. The LTE physical layer implementation follows strictly the 3GPP standard described in TS 36.211-213. Other system settings and simulation assumption can be found in our previous works [4].

A. TCO without backhaul (BH) cost

1) Overview of the TCO

The TCO of the different indoor systems along with their radio performance is shown in Figure 2. The investigated systems also include a three-sector DAS, where the signal from each base station sector is distributed on a separate floor of the building. This will increase the overall capacity of the system, but brings about additional cost due to increased base station equipment. Pico base stations are assumed as the signal source for the DAS.

The low-cost Femto has an absolute advantage by demonstrating both the lowest overall TCO and the lowest normalized TCO per MB. The DASs have relatively high TCO (due to high IMPEX) and much lower offered capacity compared to the Femto systems. The TCO of the Femto system varies largely depending on the FAP price. The high-cost Femto cost more than a single-sector DAS system. However, due to its much lower normalized TCO per MB, the high-cost Femto still achieves great advantage over the DAS in high traffic demand scenarios.

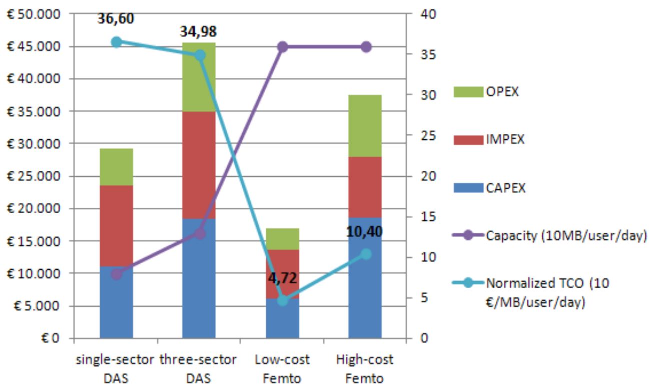

Figure 2. TCO comparison of LTE DAS and Femto

In this scenario, we focus on indoor hotspot scenario with high traffic demand. To make a fair comparison in the TCO analysis, the same traffic demand should be supported by the investigated systems. Essentially, we want to know how many sectors or Femtocells are needed to support a certain high traffic load. Furthermore, it is also important to see how the TCO increases if the system should be upgraded when the traffic load keeps growing. For this purpose, a traffic growth model with an annual accumulated traffic increase by 25% is used for a period of 9 years, presumably from 2012 to 2020. An initial in-building user traffic need of 100Mbit/user/day is taken at the first year. In the last year, the average user traffic need reaches up to 600Mbit/user/day.

According to the traffic volume increase, the expected system upgrade suggested by system performance simulations are shown in TABLE II. and TABLE III. . The simulation of DAS is conducted with up to 6 sectors; such a DAS can provide the required capacity until year 2018. Meanwhile, by deploying 18 Femto cells within the building, Femto can still meet the traffic need at the end of year 2020.

TABLE II. EVOLUTION OF SYSTEM UPGRADE WITH DAS SOLUTION.

Beginning of Year	**2012**	**2015**	**2018**
Build or Upgrade to	3-sector MIMO	6-sector MIMO	Out of Capacity

TABLE III. TIMING OF SYSTEM UPGRADE WITH FEMTO SOLUTION.

Beginning of Year	**2012**	**2020**
Build or Upgrade to	12 MIMO Femto	18 MIMO Femto

The corresponding system TCO with expected system upgrade is shown in Figure 3. According to the upgrade path given by TABLE II and TABLE III. , for Femto systems, 12 Femto cells are deployed at the beginning of the year 2012. In mid-2014, replacement of all Femto access points occurs due to the assumed equipment lifetime of 2.5 years. This is followed by another replacement in 2017. For DAS, a 3-sector DAS is deployed at the beginning of the year. In the year 2015, it is upgraded to insert new sectors, and finally, the last costs are added in 2017 due to replacement of out-dated equipment. Both systems can operate until the year 2019 before any more devices reach their life time. However, as stated earlier, by year 2018, the DAS can no longer support the required capacity and will be operating at a much lower capacity compared to Femto.

The TCO comparison of passive DAS and the Femto systems are shown in Figure 3. We can see from the result that the Femto system has an obvious advantage in this high traffic demand scenario. Both its initial cash investment and incremental cost for future system upgrade is lower than the DAS. The TCO of the low-cost Femto system is only one-third of the Pico DAS in 9 years. The DAS, especially DAS with more expensive base station devices, i.e. Macro base station, is less cost efficient than Femto in this scenarios.

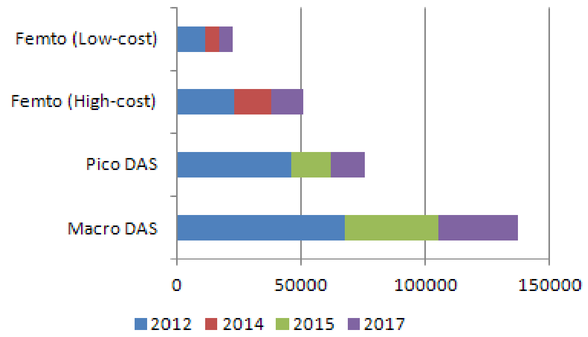

Figure 3. TCO increase with system upgrade

3) Coverage-oriented scenario

In many other in-building deployment cases, high speed data traffic occurs only occasionally. In such buildings, the main goal is to provide ubiquitous coverage and moderate data rate services. For this coverage-oriented deployment case, we study the TCO as a function of the in-building coverage area, assuming that the traffic demand can be met by the capacity of a single LTE sector.

The cost of DAS can be divided into two parts: the distributed system that is related to the coverage area and the central system which is not. The distributed system includes mainly the remote antennas, cables, couplers or splitters, etc, which has a unit price per square meter (deprived from the above results with the specific building model). The remaining part of the system is centrally located and includes mainly the base stations, backhaul equipment and power supply etc. The cost of the central system is constant for the coverage area of one sector.

The TCO result is shown in Figure 4. We sort the buildings into 3 categories: small sized buildings with total size less than 6,000 square meters; medium sized buildings with size between 6,000 and 20,000 square meters; and finally, large sized buildings if the size exceeds 20,000 square meters. We assume that the maximum single-sector coverage is up to 25000 square meters. Buildings of even larger sizes thus require multi-sector DAS. Their costs are multiplications of the single-sector cost.

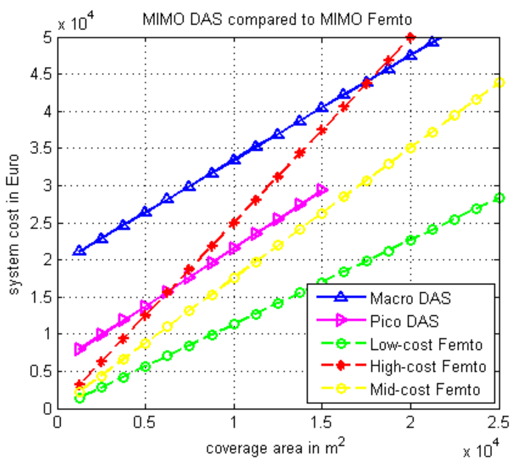

Figure 4. 5-year TCO for LTE in-building solutions as a function of coverage area

In general, the TCO of Femto system depends greatly on FAP prices. Three FAP categories are examined: low-cost with 250 € per FAP, mid-cost with 500 € per FAP and high-cost of 800 € per FAP. When the FAP price is under 500 €, the Femto system is always the most economical indoor solution regardless of the area size. If the price per FAP reaches 800 €, Femto deployment will be more expensive than Pico DAS for medium to large sized buildings, and more expensive than macro DAS for large sized buildings. For expensive FAPs, Femto deployment will only have advantage over DAS for small sized buildings where only 2 to 3 Femtocells can fulfill the coverage.

B. TCO with variant BH options

There are several optional approaches to provide backhaul connection to the in-building mobile systems: by leased line, by micro wave backhaul or by self-deployed fiber. In some dense urban places, modern business buildings are already connected to the provider's network, or are easily connected without significant extra cost. However, in most cases, existing backhaul infrastructure is not available at site; and either leasing or building self-owned backhaul link is quite costly.

For high data-rate applications, fiber is the ultimate preferred solution due to its large bandwidth. But deploying fiber causes a huge amount of cash investment. The average fiber installation cost in Europe is around 100 € per meter in dense urban environment Taking 1,000 meters as the average stretch length, it will amount to 100,000 € in CAPEX per link. The good thing about fiber is its long depreciation time of up to 20 years and its high capacity which allows the capacity to be shared with other applications such as cable TV, security alarm system and other intelligent remote controlling systems. However, so far the fiber cost is still too high to justify its vast deployment for in-building solutions. Mobile operators tend to use leased lines or build micro wave backhaul at the roll-out phase to avoid huge amount of outgoing cash flow at one time.

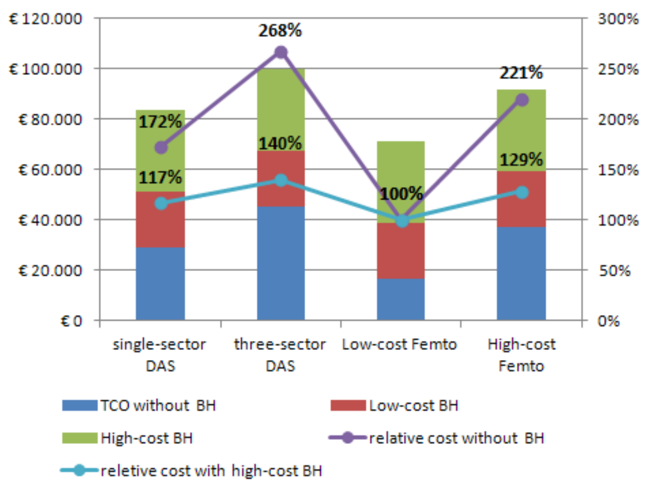

Figure 5. TCO with backhaul cost (Europe)

An example of TCO with backhaul cost in a high data-rate case is illustrated in Figure 5. In the figure, the low-cost of backhaul corresponds to a leased line of 400 € per month; and the high backhaul cost corresponds to a leased line of 1,000 € per month. After backhaul cost is applied in TCO, the advantage of Femto systems is less obvious, even for low-cost Femto cells. The relative cost increase compared to the low-cost Femto system in Figure 5, demonstrates that after high backhaul cost is added on top, the big economical gain (three-sector DAS is more than 150% more expensive) of low-cost Femto system becomes marginal (less than 50%).

C. TCO in markets with low labor cost

The TCO results presented in the above sections are deprived from cost figures that match the average prices in European markets. In other regions of the world, especially in the developing countries like China and Brazil, the labour cost is much lower than in Europe. The TCO model is set up for such markets by reducing all human resource related cost to half of that in Europe. The installation cost and network planning are largely reduced, which have a major impact on the DAS cost. The same analysis for high data-rate scenario and coverage-oriented scenario are applied to this low-labour-cost model. The results are shown below in Figure 6 and Figure 7 respectively.

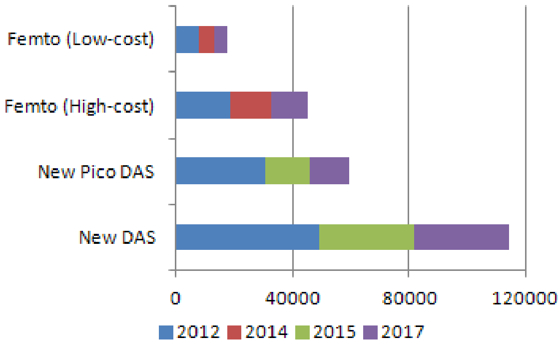

Figure 6. TCO increase with system upgrade (Developing Country)

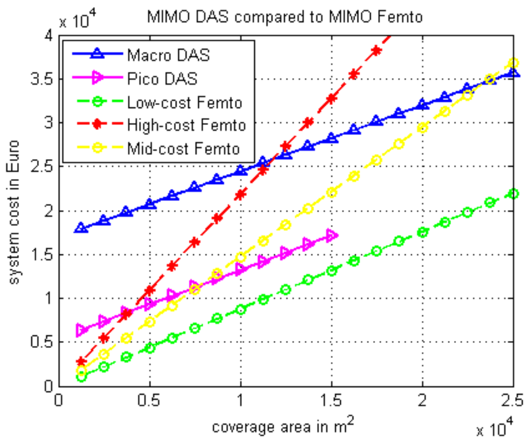

Figure 7. 5-year TCO for LTE in-building solutions as a function of coverage area (Developing Country)

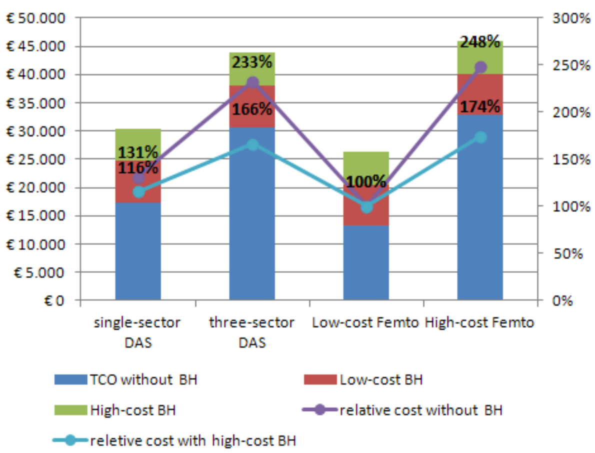

Figure 8. TCO with backhaul cost (Beijing, China)

The results show that even with reduced DAS cost, the Femto system is still the optimal solution for high data-rate, high traffic volume applications. In the coverage-oriented scenario shown in Figure 7, the TCO of DAS grows much slower than in European cases (Figure 4). The Pico DAS cost is comparative to a mid-cost Femto system for medium to large buildings. The Femto system keeps its advantage over the DAS only when the FAP price is below 300 €.

The low labour cost also affects the backhaul. Taking the example of the city of Beijing in China, the digging cost of fibre installation is as low as 6,000 € per 1.5 kilometres in the urban environment. The result of TCO including self-deployed fibre backhaul is shown in Figure 8 assuming fibre digging length ranging from 1,000 to 2,000 meters. The cost advantage of the low-cost Femto remains high in this case even after the backhaul cost is added.

V. CONCLUSIONS

In this study, we compare the TCO of Femto and passive DAS for in-building mobile networks. The different Femto cost categories are used to reflect the uncertainty in the overall Femto deployment cost.

To provide very high data-rate in-building services, the Femto system has absolute advantage over the DAS in all the scenarios due to its low cost and high offered capacity. However, when the backhaul cost becomes significant compared to other cost, the TCO of the two systems may end up in the same range and the financial advantage of Femto diminishes. The high cost of backhaul is more severe for the developed countries than in the developing countries.

For coverage-oriented deployment with small data traffic volume, the low-cost Femto is always the most economical solution. In developing countries, with high DAS IMPEX, the Femto system is more cost-efficient as long as the per FAP price is below 500 €. In developing countries, the FAP price has to be lower than 300 € to maintain its cost advantage over the DAS. For FAPs that exceeds these prices, the DAS costs less in medium to large buildings; the Femto system is beneficial only for small buildings.

In this study we consider the single operator, single radio access technology and single spectrum band only scenario. It can be expected that advantage of DAS may appear when multiple operators, multiple frequency bands or multiple radio access technologies are installed in the same system and cost of deploying the distributed system is shared. This will be included in our further work.

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