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COST ANALYSIS OF SMART ANTENNA SYSTEMS DEPLOYMENT

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***Abstract*—3G networks and services are being launched all over the world. The basic investments on equipment have already been done according to preliminary traffic forecasts. However, if the mobile data traffic acquires “internet-like” proportions, network capacity shortage will become a reality in densely populated areas, such as city centers and business parks. In that case smart antennas may be the solution. Based on this assumption the financial aspects of the deployment of smart antenna systems in the 3G UMTS networks have been evaluated. We have evaluated the potential CAPEX and OPEX savings provided by such a system compared to more conventional antenna systems. Despite their indicative nature, our calculations show that cost savings of the order of 10% to 25% are feasible if the cost increase of the smart antenna equipment is of the order of 100% to 50% of the conventional antennas equipment costs, respectively.**

I. INTRODUCTION

Enabling new and better services in a cost effective manner is a main goal for mobile operators. In order to achieve this goal by the introduction of 3G technologies, e.g. UMTS or CDMA2000, the posed problems such as network capacity shortage must be solved by the operators. Adding more base station sites is not the most efficient means of solving the capacity shortage, coverage and QoS (Quality of Service) problems. Traditional cell splitting with more sites could also reduce the throughput per site due to complex management of co-channel interference [1].

Smart antenna systems (SAS) may be the answer as the primary advantages of using smart antennas in wireless networks are to increase the number of voice calls and the amount of data throughput, to avoid interference and to ease network management. The base-station equipped with SAS works out where the mobile station is by measuring the relative signal strengths at multiple antennas. Then it can direct its transmission towards the mobile station reducing in this way the interference in the cell with impact to the overall system. Therefore, smart antennas allow the increase of user capacities and consequently profits by using spectrum and power more efficiently. Both of these depend on proper control of the antenna’s radiation and reception pattern. Increased capacity together with extended capacity and enhanced QoS are the main benefits of the smart antenna system deployment.

It has also been shown that multiple antennas provide additional improvements for both spectrum and cost efficiency [2]. In fact in paper [3] it was shown that a capacity gain of approximately 2.5 might be achieved in Urban environments, which are the most likely to suffer from capacity shortage in UMTS networks since the high population density in such areas and the propensity of users to buy new and more advanced services.

Hence, the main objective of this paper is to analyze the potential economical return gained by the implementation of SAS in UMTS networks utilizing the FDD mode. The analysis comprises typical capital expenditure (CAPEX) and operational expenditures (OPEX) of an incumbent network deployed in Urban environments for two deployment strategies one with conventional sector antenna systems (CAS) and the other with smart antenna technology in base stations.

The cost model is based on assumptions that in general could be applied to any medium sized UMTS network operator and is partially based on the approach developed by TONIC [4]. The cost model was further revised in the Low Cost Infrastructure (LCI) project organized by Wireless@KTH in co-operation with TeliaSonera Mobile Networks R&D and Ericsson Research [5]. The particular cost analysis approach is based on models provided in [6], [7] and [8].

The following questions have been posed:

Given a traffic demand what cost savings are anticipated by the deployment of smart antenna technology in urban environments?

Which costs do represent the largest burden and how can smart antennas alleviate it?

Given a cost saving target, traffic demand and a smart antenna technology with known performance in terms of capacity gain what is the maximum allowable equipment cost?

II. METHOD AND ASSUMPTIONS

A discounted cash flow model is used in the cost analysis where only investments and operating costs are considered as input data.

The investments comprise capital expenditure on equipment and related network infrastructure. The operating costs are divided in operational, maintenance and personal costs, which are directly related to infrastructure costs; marketing costs, which in general include customer acquisition

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and handset subsidization and the content part too, which includes product development and content acquisition.

Further, the investment costs are derived from the capital expenditure and are divided in the following steps. Firstly, the traffic profile (or yearly traffic demand) over the considered time span is estimated, which takes into account user penetration, mobile penetration, the UMTS market share and user population density in a given environment. Secondly, the radio access network (RAN) is planned also on a year basis and will have as input the traffic profile, which will dictate the need for incremental additions of network elements such as Node Bs (NB) and Radio Network Controllers (RNC). It is worthwhile to notice that providing the proper network configuration that meets traffic requirements and minimize network costs at the same time is not trivial. Many parameters have to be taken into account such as number of carriers, number of sectors, loading; number of users and cell range which all have an impact on the final result.

The operational and maintenance costs include the OPEX related to the investment costs and it is assumed that the marketing and the content costs are each 33 % of the total operational cost. The CAPEX and OPEX for some of the network resources are calculated over a period of 15 years.

As the aim being to estimate the impact of smart antennas on the UMTS economics the procedure described above is repeated for different values of the following parameters: the capacity gain provided by the deployment of Node Bs equipped with Smart Antenna Systems, the cost of the equipment and the average traffic demand per deployment area. In the present analysis the focus has been on the radio access network (RAN) and refrains from assessing the core network (CN) impact. However, the CN nodes are of course vital components that must be reconfigured and upgraded as the traffic demand increases.

A. *Traffic Profile*

In order to calculate the traffic profile during the busy hour per unit area, that is Mbps/km^2 several factors have been taken into consideration. The two principal components considered are, the user density, which is the number of users per squared kilometer and the average traffic generated per user during the busy hour. The user density is modeled as the number of potential costumers located in a given area, in our case, the urban environment. The model is summarized in the following equation,

$$Traffic_k = \left(up_k mp_k ms_k u_k p_k at_k\right)/S_k \qquad (1)$$

In the equation above the index k denotes the year in question, up_k is the user penetration, mp_k is the mobile penetration, ms_k is the UMTS market share, u_k is the percent of all the population living in urban environments, p_k is the population of small country, S_k is the service coverage area and at_k is the average traffic during the busy hour.

1) *Mobile Penetration and UMTS penetration*

The mobile penetration is assumed to increase by every year with a saturation level at about 90% of the population. There is a 10 % of the population: children and elderly that are unlikely to ever use mobile phones regardless the service provided. The UMTS penetration is modeled according to estimates in [7&8] with a peak at 90 % within 10 years with a decline after that due to the introduction of next generation systems. The author has used the estimates provided in [7&8] though a delay of two years has been assumed.

2) *Market Share*

The market share profile has been properly accounted for.

3) *Inhabitants*

The population is assumed to increase with 0.35% each year; however the population in densely populated regions will increase at a higher rate which is expected to be around 1% yearly. It is also assumed that 21% of all the inhabitants populate the urban environments.

4) *Traffic Forecast*

One of the most important parameters used in order to assess the techno-economical aspects of a UMTS network is the traffic distribution and the traffic forecast during the busy hour (see Table. I below), since they will determine the capacity of the network to be dimensioned for. The capacity demand is calculated from the superposition of the demands related to individual services and both business and private users must be considered. In addition, the different services may have different trends and different start-up times. However, here we will assume just the resultant of such superposition and will not take care of the evolution in time of each specific service. The average traffic per user (including business and private consumers) under the busy hour was obtained from a UMTS Forum report [9] which recommended approximately 1 Kbps/user. The number corresponds to the traffic forecast for year 2010. We further extrapolated the model by considering a traffic rate increase of 6 % yearly, which spans from year 2003 to year 2017.

TABLE I.

Traffic Forecast		
Worst Case Busy Hour	***Uplink***	***Downlink***
Average per subscriber	198.4 kBytes	454.9 kBytes
Business subscribers	361.4 kBytes	808.7 kBytes
Consumer subscribers	106.4 kBytes	255.1 kBytes

III. RAN PLANNING AND INVESTMENT COSTS

Here a simplified network planning approach has been adopted. In general the RAN dimensioning starts with link budget calculation, which provides the maximum allowed path loss thereby the maximum cell range is estimated depending on the propagation environment characteristics, further the cell capacity is estimated having into account the peak traffic and the loading factor which is also output of the capacity estimation process and is computed iteratively. Finally, the equipment requirements in terms of BS and RNC are derived.

The network is deployed with three-sectored sites only, each sector covering a circle-shaped cell (or hexagonal cell). The cell range is set to 0.32 Km as an example of average cell radius in urban environments in the initial phase of the UMTS network deployment (the cell range depends in general on the number of simultaneous users in terms of interference margins and the antenna performance of the user equipment for instance). We further assume that traffic density will be uniformly distributed over the coverage area, which is 650 km^2, which is the approximate area covered by the UMTS sites in urban environment in a small country.

The number of Node-Bs is then calculated in order to jointly satisfy the coverage profile and the traffic profile. This means that each year starting from year 2003 the minimum number of sites required is calculated. The traffic during the busy hour is modeled as mentioned in the section A. above giving a traffic demand for each year and it is assumed that full coverage will be provided from the first year. Further, after estimating the number of Node-Bs the deployment of additional carriers is assessed in order to satisfy the traffic demands. The whole network is then divided in different regions one of each is handled by a single RNC. The RNC dimensioning will provide the number of RNCs needed to support the traffic demand, which is limited by the maximum number of Node-Bs it can serve and the maximum Iub (interface between the Node B and the RNC) throughput and the amount and type of interfaces. The length of the leased lines is calculated approximately assuming that it equals the distance between the RNC and the Node-Bs. It is further assumed that the RNC is located in the center, with Node-Bs located in circles around.

TABLE II.

Equipment Costs		
Equipment	***Cost 2003 [k€]***	***Capacity***
UMTS RNC	1500	250 Mbps or max 100 Node-B/RNC
UMTS Macro Node-B, one sector	70	1 Mbps
UMTS Macro Node-B, additional sector	30	1 Mbps
UMTS Macro Node-B, additional carrier	20	1 Mbps

TABLE III.

Installation & Build Out Costs	
	Cost 2003 [k€]
UMTS Macro Node-B site installation	35
UMTS Macro Node-B site build out	100

TABLE IV.

Running Costs			
	Cost 2003 [k€]	***Capacity***	***Variable Annual Costs***
Site lease, UMTS Node-B Macro	9		
Leased Line, E1	6	2 Mbps	0.54 k€/ km line
Leased Line, E3	12	30 Mbps	1.68 k€/ km line

The costs are divided in three categories: equipment costs, where cost for Node-Bs for one sector, and the cost of additional sectors and additional carriers is included, installation costs that are subdivided into the costs for installing new equipment only and build out costs, finally we have the running costs, which includes the site lease, and transport interface lease as well as cost for leased lines. Typical expenditure values in agreement with those used in [4&5] are given in tables II, III and IV.

In order to estimate the CAPEX and the OPEX 5 % price erosion has been assumed, while the discount rate equals 10% and a maintenance expenditure of 5 % of the total aggregate investment has been added per year for all equipment. Finally we have assumed that running costs are not subject to price erosion.

IV. CAPEX & OPEX - RESULTS

The assessment of the financial soundness of an inversion is of crucial importance in order to achieve the established business goals. Therefore, the focus has been on the potential cost saving in terms of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) that potentially could be achieved by the deployment of smart antenna systems in the medium size UMTS network in a small country. Despite the technological supremacy of one solution compared to the other, the cost aspect will be the driving force when it comes to the business implementation. Our aim is to provide a general analysis of what is feasible in that respect by answering the questions posed in the introduction.

CAPEX and OPEX as function of both the smart antenna system capacity gain and the cost increase of smart antenna equipment relative to conventional antennas cost for three traffic profiles have been calculated. The first one is the baseline traffic profile denoted by Co (see equation (1) and Table. I), the second one is three times Co and the third one is ten times Co. The base line traffic profile (Co) is what has been assumed in our model with the peak our traffic demand per user corresponding to the UMTS Forum forecast [9].

A yearly investment analysis shows, (not provided here due to lack of space), as expected, that the both CAPEX and OPEX increase with the SAS equipment costs and the traffic demand. On the other hand capital and operational expenditures will decrease as the SAS gain over CAS increases, though only if the initial planning cannot reach the traffic demand as in the case of the 10Co traffic scenario. This suggests that SAS should be deployed mainly in areas with high concentration of users, that is highly dense Urban Areas or Business Parks where users are expected to generate a large amount of data traffic, a double as much per user as private consumers.

TABLE V.

10Co Traffic Scenario Smart Antenna Systems Capacity Increase by factor 2.5						
Node B Cost Increase	100%	80%	60%	40%	20%	0%
CAPEX saving	10%	17%	24%	31%	38%	45%
OPEX saving	13%	18%	22%	26%	30%	34%

Hence, in the following results for the 10Co scenario only will be considered. The SAS solution providing a 2.5 capacity gain over the CAS solution was evaluated and the obtained cost savings are provided in Table. V. As can be seen if the SAS equipment cost would be the same as CAS system the overall relative cost saving will be as high as 40% on the other hand if the SAS cost is doubled (100% cost increase) there will be still a cost saving of around 10%, which may be a considerable amount of financial resources, that could be used in other profitable investments related to the UMTS services. Hence, results given in Table. I answer the first question i.e. "Given a traffic demand what cost savings are anticipated by the deployment of smart antenna technology in urban environments?"

The answer to the second question is obtained by further looking into the internal cost distribution over the systems' life span, for a system equipped with smart antennas that is 1.8 times more expensive than the system with conventional sector antennas. It was obtained that in the case of CAS the initial investment will provide capacity through coverage so the systems are over dimensioned with only one carrier deployed. However, already after five years in order to meet the increasing traffic demand new investment must be done, which are reached by adding new carriers. This would apparently solve the problem but in practice new ones will be added since additional carriers may introduce further interference and cause coverage and capacity shortages. Further, more RNCs most be deployed in order to take care of the increasing data traffic. After some years from the start no more spectrum will be available so new sites must be deployed and with that extra costs expected. The need of new sites will also impact negatively the overall interference scenario and the overall planning will become a hard task. Additional carriers must be added as well as new sites must be acquired again worsening the whole situation. The OPEX will also increase since new sites must be acquired. The costs for leased lines remain almost unchanged and are subject only to discount rates. In other hand, for smart antennas the CAPEX was concentrated to the initial investment. The costs due to RNC are the same as in the CAS case since the same traffic scenario has been assumed. However, after some years new investments must be done since the traffic demand is not fulfilled, and a new carrier must be deployed. However, no more sites are acquired in this case and both CAPEX and OPEX costs due to build outs are avoided.

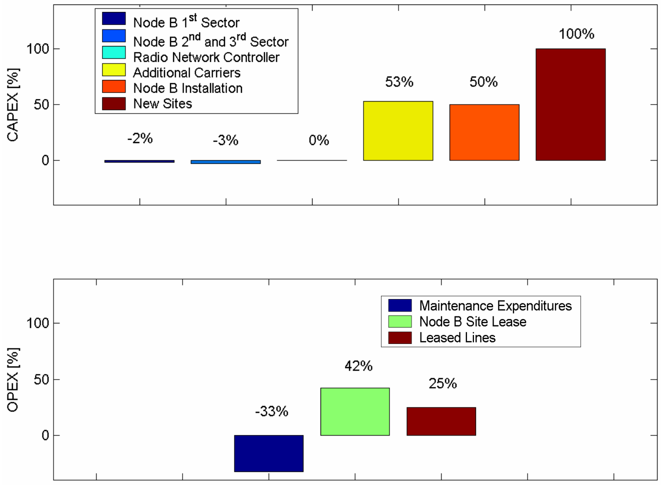

Figure 1. CAPEX and OPEX reduction obtained by the deplyment of smart antenna systems relative conventional smart antenna systems

The comparison is summarized in Fig.1 through Fig.3. As is clear from Fig.1 the equipment cost is slightly higher (around 3%) for the SAS deployment compared to CAS. The maintenance expenditure is also higher (33%) for that system since it is directly proportional to the equipment costs. The cost due to RNC is the same (0%) since the same traffic demand must be met in both deployment scenarios. So the main cost savings come through the fewer site acquisitions, which will impact on the build out costs (no new sites are needed so a 100% of costs of new sites are saved), Node B installation costs (50%), leased lines (25%) and site lease (42%).

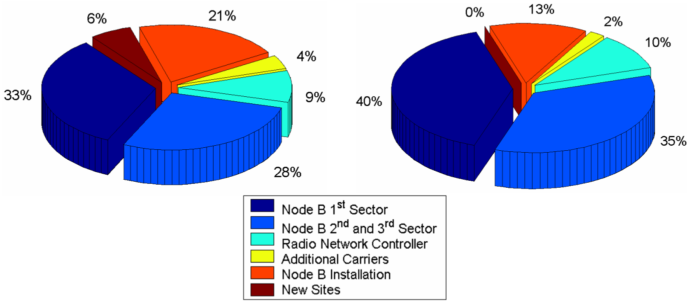

Figure 2. CAPEX distribution for Conventinal (Sector) Antenna Systems(left) and Smart Antenna Systems (right)

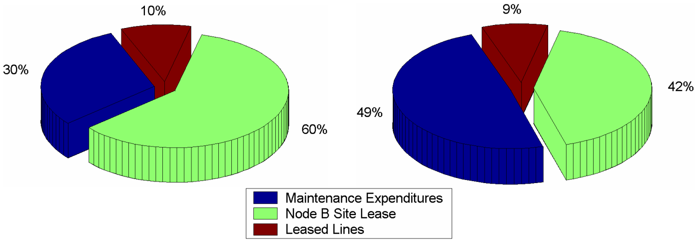

Figure 3. OPEX distribution for Conventinal (Sector) Antenna Systems(left) and Smart Antenna Systems (right)

The internal distribution for CAPEX is shown in Fig2. It is clear that the equipment costs will be higher relative other costs for he SAS deployment since, for instance, no new sites are acquired, which has a direct impact on OPEX due to higher maintenance expenditures.

The third question posed in the introduction addressed the potential cost saving provided by the implementation of smart antenna technology given a traffic demand forecast, the capacity gain over conventional antenna systems and their relative cost increase.

It was noticed that for larger traffic demand and higher equipment costs the larger was the CAPEX and OPEX, which is more significant for less sophisticated antenna systems. Further, as the "IQ" of the Node B is boosted the relative cost increase gets insignificant relative the "less gifted" system since further system capacity gain will not provide any additional profit if the required traffic demand is already met. It is clear that the cost saving in terms of CAPEX and OPEX is directly proportional to the average year traffic and the system capacity gain provided by a smart antenna technology though it will as expected be inversely proportional to the equipment cost increase.

Hence , in order to find such "simple" relationship CAPEX and OPEX calculation were repeated for different equipment cost increase for ten traffic profiles, which are multiples of the basic traffic profile Co and different smart antenna system capacity gains. Results are presented in Fig.4, which displays the cost savings in percents as function of the average traffic demand taken over the period of interest divided by the cost factor of the smart antenna equipment. Results for two different systems are provided; the one improves the capacity performance of NBs by a factor 2.5, which could be achieved by an array of switched beams in urban environments and the second by a factor 5 that could be obtained with more sophisticated antenna system technologies like e.g. MIMO. The cost saving is calculated relative to the same traffic scenario for different values of the equipment cost increase. It is easy to see that the cost savings seems to be bounded from below and this "bound" (observe that no mathematically strict bound is provided, but it is still intuitively correct) will be different for different systems implementations. In other words the higher SAS gain provided the higher the minimum achievable cost saving.

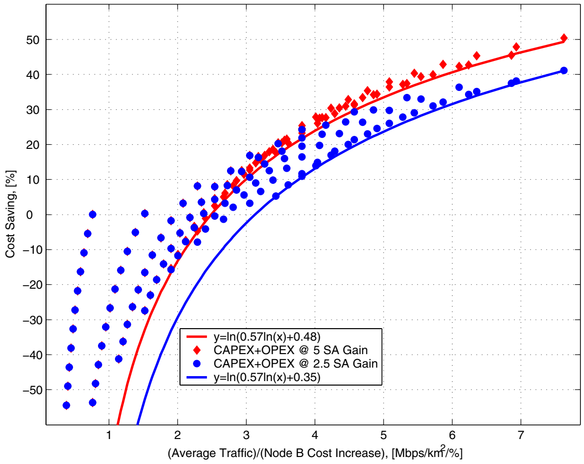

Figure 4. Cost saving in percents as function of the average traffic load divided by the relative BS cost increase

Let denote the minimum cost saving by κ then according to the definition given above we found that a fitting equation could be expressed as follows:

$$\kappa \le \ln\left(\alpha \ln\left(\lambda/c\right)+\beta\right) \tag{2}$$

The constants α and β in equation (2) depend on the capacity gain provided by the smart antenna system. The average traffic demand (λ>0) taken over the period of interest divided by the cost factor of the smart antenna equipment (c≥1). The positive κ means that there is a decrease of capital and operational expenditures, on the other hand negative κ indicates additional expenditure costs. Now let say that we have a target cost investment saving (and related operational) of 10%, and then solving the above equation we obtain: $\lambda/c \ge e^{\left(e^{\kappa}-\beta\right)/\alpha}$. Substituting of the numerical values we obtain that in order to achieve the 10% saving target, the maximum cost factor for the same traffic demand may be higher for the system providing higher capacity gain, which was expected as illustrated by equations below,

$$c_5 \le \lambda/3 \tag{3}$$

$$c_{2.5} \le \lambda/3.76 \tag{4}$$

For instance if the average traffic demand equals 5 Mbps/km^2 then in order to achieve a 10% CAPEX plus OPEX reduction the smart antenna equipment cost should not exceed the 66% increase for the system providing 5 times the capacity of CAS and 33% if it provides a factor 2.5 capacity gain. Conversely, if the equipment cost is known the minimum average traffic demand required in order to meet the cost target may be estimated. It is also clear that for the same "average traffic-to-cost" ratio doubling the system capacity gain from 2.5 to 5 may provide additional 10 % in CAPEX plus OPEX reduction.

V. CONCLUSIONS

A more efficient and flexible network infrastructure could be build with the help of smart antennas, though with the condition that sufficient amount of data traffic is generated by the UMTS users. Factors that will increase the traffic are as mentioned above the mobile penetration, the UMTS penetration but what is more relevant is the market share, the per-user traffic density, which in turn are triggered by new better services. Therefore sufficient network capacity must be available through higher capacity gain. However this capacity is most likely to be needed only in highly dense urban environments but even more in technical parks and business centers where large amount of business users have their work place. Therefore our results would likely to apply, with typical small country UMTS network in mind only to a small portion of sites that will be between 1 to 5% approximately and mostly in hot spot scenarios.

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