Can crowdsourced WiFi be a viable strategy to provide open internet access in a municipality?

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***Abstract*—This paper analyzes the business case of a "crowdsourced" municipal Wi-Fi network. It aims to answer the question if a positive business case is feasible for a municipality that aims to deploy such a network and if crowdsourcing it can generate a reduction in the network's total cost of ownership (TCO).**

In a crowdsourced network a community of people share their domestic broadband connection with eachother using the commercially available Wi-Fi standards and through a captive portal the network becomes available to other users as well such as tourists, commuters, etc...

The paper looks specifically at the case of the city of Ghent (Belgium), for which data and a cost benefit model are available. Comparing the crowdsourced network to a traditional rollout in which a single party places industry grade base stations throughout the city shows that indeed a significant reduction in TCO can be obtained. Further it is shown that the business case for Ghent can be deemed favourable. A Monte Carlo based uncertainty and sensitivity analysis corroborates the robustness of these results.

I. Introduction

Municipal Wi-Fi is the idea to let a wireless network cover the municipality. Such a network is believed to benefit the municipality and its inhabitants in various ways. Universal internet access, bridging the digital divide, e-government services are amongst the cited motivations. An overview and deeper analysis can be found in [1] and [2].

Multiple business models can be used to deploy such networks. These models, not seldom with an important role for the local government, differ from eachother in initiator, used technology, leading motivations and other aspects. Previous work by the author [3] identifies integrator, wholesale, public service and community models as possible approaches.

This paper focuses on a specific implementation of the community model: the "crowdsourced" Wi-Fi network. In the crowdsourced model, also called "Wi-Fi sharing" the access network is made up of a community of people who share their domestic broadband connection with the community using the Wi-Fi standards. They attach a wireless router to their Local Area Network (LAN) containing firmware that allows an easy setup, a universal network identifier, priority rules for the LAN, redirection to an authentication portal and other functionalities.

This paper aims to analyze (A) if there is a positive business case for a local municipality that aims to deploy a wireless network and (B) whether or not involving its inhabitants in a crowdsourced project is a financially more attractive way of accomplishing this than relying on a more traditional rollout in which a public private partnership (PPP) installs industry scale outdoor base stations (BS) that are connected to the municipality's communication network.

II. Approach & Organization

The results of these analyses are obtained from the calculation of a sample case for which a cost benefit model was developed: a rollout in the city of Ghent, the second city in the Flemish northern half of Belgium. Valuable data and research on this case is at hand through an interdisciplinary project the authors are involved in researching the economic, technical, institutional and legal feasibility of a green wireless city network cornered around sensor applications and "Wi-Fi sharing" (GreenWeCan Project, cfr. Acknowlegement).

The paper is organized as follows. The model, calculations and the data are explained throughout the following two sections. The first of these two sections (section III) focuses on the comparison of the different rollout strategies in light of the project's total cost of ownership (TCO). This section tries to answer the question whether or not crowdsourcing the Wi-Fi network provides financial benefits. Section IV analyzes the complete business case in Ghent contemplating revenues as well.

The robustness of the results from these analyses is researched in section V. This section offers a Monte Carlo based uncertainty and sensitivity analysis of the model's output with respect to uncertainty in the inputs using First Order Sensitivity Indices [4]. Section VI finally concludes the paper with an overview of the most important observations and a take on future research.

III. Can crowdsourcing significantly reduce the TCO of a municipal Wi-Fi network?

The key difference between the traditional approach and the crowdsourced approach in light of the project's finances is a difference in equipment. In the traditional scenario, the city will subcontract (or initiate a PPP with) a network operator that will install performant outdoor BSs on tall city owned buildings and connect them to the city's telecommunications network [1].

[1]Note that is assumed that, as is the case in Ghent, the municipality already owns a (fiber optic) communication network that can be used for backhauling. If this is not the case additional backhauling costs need to be calculated further deteriorating the traditional approach

In the crowdsourced approach the city purchases (or develops) crowdsourced Wi-Fi enabled access points (APs) and distributes them over its population [2]. The specifications of the BSs explain the difference between both approaches. The former are performant and require a lower density to guarantee full coverage, but are more expensive and the latter are inexpensive APs with a smaller coverage due to a lower antenna gain or being placed indoors.

In the benchmark case three types of equipment are considered: The Wavion WBSn family [6] which functions as outdoor high performance BS and two crowdsourced enabled home devices. The Wavion BS is used in the ZapFi network in the city of Brugge. For the crowdsourced enabled devices an analysis of the current market for domestic broadband is made. Households with an existing domestic broadband connection can simply attach a Wi-Fi AP to their existing LAN. Households without domestic broadband or with a provider that disallows connection sharing can switch to a bitstream oriented provider[3] and attach an integrated Modem / Wi-Fi solution. These options lead to the Fonera Simpl [7], [8] and the Sagem 3464 [9] respectively. The latter is used by Belgacom, a key player in the Belgian market, that is also rolling out a crowdsourced Wi-Fi network.

For each of these BSs the range is calculated using the Erceg C [10] path loss model using the product specifications found online. For the Wavion device pricing is obtained from an interview with ZapFi CEO Gerry Pollet [11]. For the other devices the only prices at hand are consumer prices found online. An estimation is made for the installation cost as well. The Fonera Simpl is assumed to be perfectly plug and play and hence no installation cost is used. For the Sagem a technician is assumed to take an 1.5 hours and for the Wavion 1.5 days. Combined, this information allows us to dimension the network and calculate the capital expenses (CapEx) of the project.

The operational expenses (OpEx) can be calculated as well. These include server rental, BS replacements, advertising, wages, office space and other personnel overhead. These are all modeled using a driver based approach with the project's user base as principal driver. The user base is calculated using sigmoid adoption forecasting functions. This approach which is even more important for the revenue side of the model is treated in section IV.

The sum of the OpEx and CapEx posts allows the calculation of the project's discounted TCO which is calculated for Ghent's inner city with a horizon of 10 years starting in 2013 and an annual discount rate of 10%. For reasons of comparison, this result is normalized to the the yearly cost to cover 1 square kilometer of urban territorium. This procedure is repeated for three rollout strategies in which the total area is covered using each of the three types of BSs exclusively. The strategies are called "outdoor", for the traditional approach using the Wavion BSs, "indoor" for the crowdsourced approach using the Fonera APs and "integrated" for the crowdsourced approach using the Sagem APs. Figure 1 shows the comparison and breakdown of the costs for these scenarios.

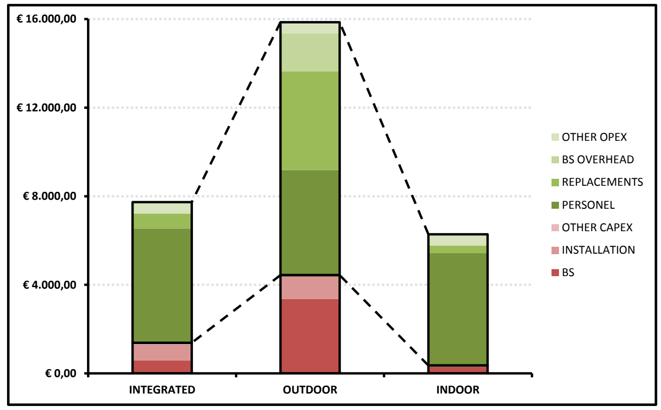

Fig. 1. Comparison of yearly coverage cost of a square kilometer of urban land

It is clear from this figure that the TCO can be significantly reduced in the two crowdsourced Wi-Fi scenarios. Reductions of 45% and 52% respectively can be obtained. Closer inspection shows that the reductions are about 60% due to OpEx and 40% due to CapEx. The former are mainly explained by the replacement costs of defective BSs as well as the overhead cost generated per BS which is estimated at EUR 150 per BS. This overhead cost can be neglected in the crowdsourced scenario because they are externalized and insignificant for the individual participating household. The difference in CapEx at the other hand is mainly explained by a reduced BS cost which is in the crowdsourced scenario 6 to 10 times lower per square kilometer despite the lower number of BSs in the outdoor scenario, 16 per km^2 versus 80 in the integrated case. The price per BS, however is significantly higher in the traditional or outdoor scenario, EUR 2000 versus EUR 85.

The difference between the indoor and integrated cases can be sufficiently explained by a difference in equipment costs, the integrated devices are more expensive as they include an AP as well as a modem and are not entirely plug and play: an installation by a technician is required in case of a new broadband subscription.

These results prompt the conclusion that it is financially preferable for the municipality to opt for the crowdsourced Wi-Fi strategy which is probably a hybrid form between the integrated and indoor scenario. This conclusion holds even if the network operator can use an existing municipal backhaul connection and the Wi-Fi sharing BSs have to be financed by

[2]Note that in some crowdsourced networks, such as the FON network [5] the equipment is purchased by the participant and not by the operator, if this is the case it further improves the business case of the crowdsourced approach from the municipalities viewpoint

[3]A lot of operators explicitly prohibit Wi-Fi sharing which made us consider the option of the municipality becoming its own (virtual) network operator. Such an endavour is subject to severe regulation. These legal aspects and other pro's and con's of the different rollout strategies such as the problem with right of way are currently being research within the GreenWeCan project but are outside the scope of this paper.

the local municipality. Nevertheless it is important to operate within the legal constraints which have to be investigated in further research or by the municipality's council.

IV. Can a positive business case be found for a municipal Wi-Fi network in Ghent?

Having shown that the crowdsourced approach can indeed reduce the project's TCO significantly it still remains to be answered whether a municipal Wi-Fi network can be made into a profitable business case. This section aims to answer that question.

In order to do so it is essential to analyze the revenues generated by the network. In the literature the distinction is made between direct and indirect revenues. Direct revenues are revenue streams that follow from the execution of the project's core activity whereas indirect revenues are not directly linked to the core activity but benefit the city, its inhabitants and its entreprises nevertheless.

Two static NPV analyses are performed for the benchmark case, one solely taking direct revenues into account and one including an example of a quantifiable indirect effect as well: the reduction in backhauling cost of a wireless sensor network that can be obtained. Both analyses focus on the crowdsourced approach using the "indoor" strategy as described in section III. The assumption is made that the network will be deployed throughout 12.5km^2 of Ghent made up of the historic city center and several highly frequented areas: two railstations, a cultural centre and a park.

A. Isolated business case

The approach to analyzing the business case is by calculating the TCO, the different revenue streams and joining them in a cash flow analysis which calculates the Net Present Value (NPV), Return On Investment (ROI), Internal Rate of Return (IRR) or other measures based on the cash flows generated by the project. In this analysis the IRR is used which is the hypothetical discount rate that would set sum of all discounted cashflows to zero: the higher the IRR the more profitable the project.

For the TCO the same calculations are used as in section III. To calculate the revenues an adoption analysis was performed based on a survey within the GreenWeCan project which provided an estimate of the market potential. Three adoption potential parameters were estimated: the potential percentage of users willing to use the network without explicit willingness to pay, the potential percentage of users that are willing to pay to use the network and the potential percentage of users willing to share their own domestic broadband connection. Note that this last fraction is about 45% and sufficiently exceeds the amount of BSs required. This renders the project feasible from a sharing point of view.

Based on these adoption potential estimates one is able to model sigmoid adoption curves following the Bass specification [12] which is given in the equation below. In this equation m stands for the adoption potential, p is the coefficient of innovation and q is the coefficient determining the importance of imitation. For m the estimates from the survey are used. p and q can in principle be estimated using the cumulative timed intent (CTI) approach from [13]. However no CTI data was collected so usage was made of the coefficients provided by [14].

$$S(t) = m\frac{1 - e^{-(p+q)t}}{1 + \left(\frac{q}{p}\right) e^{-(p+q)t}} \quad (1)$$

Effective uptake is calculated by applying these adoption curves to Ghent's population including students, commuters and tourists. Instead of fixing the average revenue per user (ARPU) and multiplying it with the uptake in order to calculate revenues, this approach would require an exact estimate of the ARPU which is given our limited survey unfeasible, we evaluated the project's IRR for a range of ARPUs.

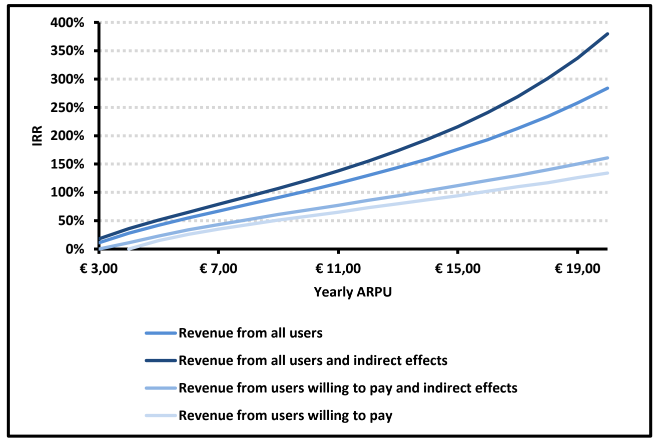

Fig. 2. Relation between project's ARPU and IRR

Figure 2 shows these results. Two calculations are made. One in which the ARPU - IRR relation is calculated for each user, and one for which the ARPU - IRR relation is calculated for those users of which willingness to pay can be infered from the survey. The figure is limited to those ARPUs that yield a positive IRR. The difference between both is that some people indicated only to use the network if it is free of charge.

The feasibility of the project can now be assessed by inspecting these ARPUs that generate a profitable project and look at their attainability. For the situation in which the network access is paid for and the user base is restricted to the willing to pay, one sees that the annual charges that would be made are significantly lower than the costs of a normal data subscription in Belgium (EUR 100 and upwards). The network however is restricted to Ghent and should not be seen as competition to the mobile phone incumbents. Nevertheless it seems plausible enough that inhabitants of Ghent and people who frequent the city are willing to pay up to EUR 20 yearly to benefit from unlimited access in Ghent.

If the aim is to provide a network free of charge and the ARPUs should come from elswhere one can assess its feasibility by looking at a second relation which calculates

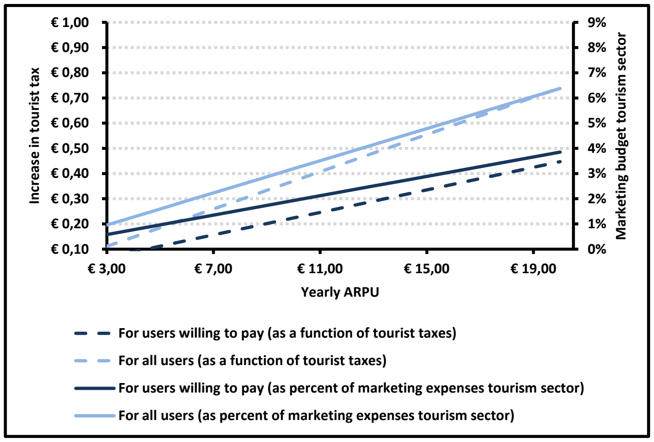

Fig. 3. Relation between the project's ARPU and Ghent's tourism sector

the connection between these ARPUs and the tourism sector. Municipal Wi-Fi is often believed to benefit tourists as they face higher roaming fees for their mobile connections. This prompted the calculation of the percentage of yearly marketing budget that the tourism sector has to invest in advertisment on the network to yield these ARPUs if the network is otherwise free of charge. Another relation that is calculated is the increase in tourist tax (this is a tax paid per night, per guest in hotels, hostels and bed and breakfasts) that would yield these ARPUs.

Figure 3 shows this relation and illustrates that the ARPUs can be obtained by an increase in tourism tax between 10cent and 70cent per night. (Ghent yearly has about 700 000 sleeping guests) [15]. Similarly a reallocation of 1% to 10% of marketing investments in tourism could yield the same benefits assuming a tourism marketing budget of 5% of the annual turnover. These figures indicate that the ARPUs required for a positive business case can indeed be obtained and that a positive business case is a realistic prediction.

B. Business case including indirect effects

The previous paragraph shows that a positive business case is possible solely based on ARPU. The business case however can be ameliorated by taking into account the indirect revenues generated by the network as well.

In the benchmark case the effects are calculated that such a network could have for a wireless sensor network provider monitoring the availability of outdoor parking spots throughout the city. This analysis can be extended to other sensors networks as well. Examples are garbage bin monitoring, traffic control, polution control, etc...

In the case of parking spot monitoring the availability of parking spots is measured with a sensor that has two states: occupied or available. Whenever this state changes and at regular intervals, the state is relayed back to the server. This server in turn can be queried by different applications. Possible applications are guidance systems on mobility devices such as GPS's and smartphones which direct the user to the closest available parking spot. But ticketing and negligence to pay can be monitored as well allowing for facilitating the work of the parking guards, increasing the probability to get caught and reducing the amount of ticketless parking.

A thorough analysis of this business case can be found in [16]. It concludes that the business case is positive and the increase in revenue will be fourfold. The application itself will generate sales, the application will increase the revenues from fines as well as the revenue from regular tickets: more people will pay for their ticket, out of fear of getting caught, and a greater fraction of the ticketless will get fined. The fourth benefit is reduced traffic in the historic city center because people prefer cheaper parking outside the city in combination with public transport.

In the case described in [16] backhauling takes place according to the following model. The parking sensor nodes use a custom multihop connectivity protocol to relay data to a gateway node of which there is about one for every 25 parking nodes. These gateway nodes in turn connect back to 20 BSs all over the city using Wi-Fi and those BSs are connected to the central office by leased lines which are assumed to cost about EUR 3500 each. So the total backhauling cost is about EUR 70000 yearly.

If a Wi-Fi network is already available those leased lines are redundant and this cost (EUR 70000) could be gained. This approach however neglects the fact that more economical alternatives are currently at hand to backhaul the sensor data. Redimensioning the sensor network shows that the backhauling could also be provided by a lower amount of gateway nodes (improved range) which connect to the backoffice using a machine-to-machine mobile data subscription with a cellular operator. Under the assumption that the 18000 sensors each send 4 updates an hour this implies a license for 20GB yearly volume for 255 sim cards. At a quote of EUR 0,70 per MB this comes down to a yearly cost of EUR 14000 that can be saved by installing a municipal Wi-Fi network.

The relation between ARPU and IRR for the calculation including indirect revenues is added to figure 2. It clearly shows an ameliorated case but with similar conclusions: a rollout is likely profitable. The more cities get digitalized, the more sensor networks they deploy, the higher these indirect revenues will be.

V. Robustness

In this section the consequences of input uncertainty are analyzed. Do the conclusions that crowdsourcing is a viable strategy and that a possitive business case can be obtained for the Ghent scenario still hold if the parameter values are not what they are estimated to be? What source of uncertainty has the biggest impact? An answer to these two questions is searched using uncertainty and sensitivity analyses respectively. Both the analyses are performed in Monte Carlo based experiments in which uncertainty is added to some of the model's parameters by means of a probability distribution from which a few thousand repeated samples are drawn.

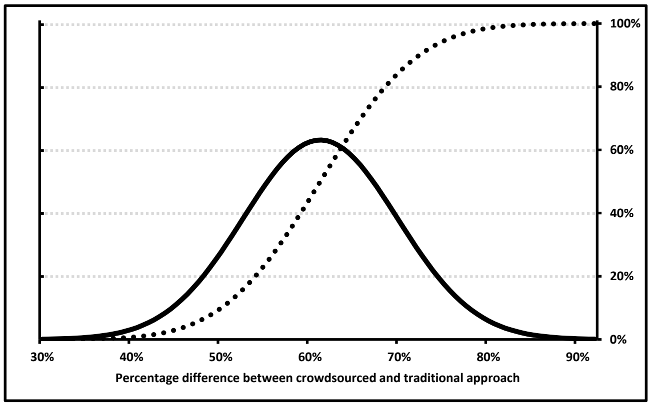

Fig. 4. Distribution of difference between Operator and Crowdsourced model under uncertain inputs

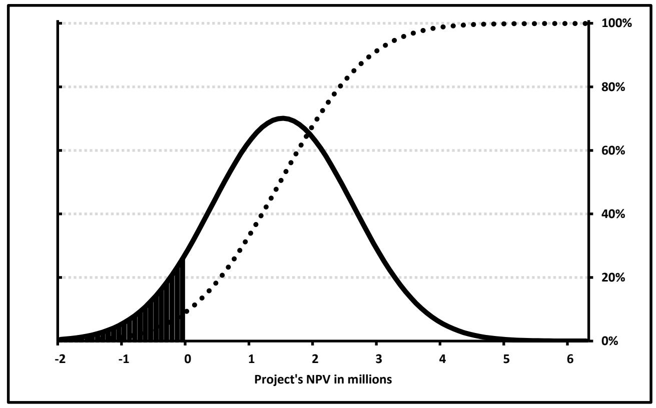

Fig. 5. Distribution of NPV (in millions) of project under uncertain inputs

A first notable variable for which uncertainty is added is the range that can be covered by an individual BS. As explained in section III, a value for this range is calculated using the Erceg C path loss model. This value however is only an approximation, as path loss models fail to take into account certain specificities of the urban terrain and environment such as the placement of buildings, trees and other factors that could obstruct line of sight and signal propagation.

A second important source of uncertainty is found in the adoption related data. Section IV for example illustrates the difficulty of obtaining ARPU estimates. Further also the adoption parameters are not trivially forecasted: in the presented research values are obtained from the literature [14] but even if cumulative timed intent data is available and the method from [13] is used, the predictions are not exact.

The next set of variables for which uncertainty is introduced are the component costs and prices. The NPV analysis makes use of price quotes obtained from network providers [11] as well as end user prices found online for the consumer grade APs. These prices however are not exactly what the municipality would pay manufacturers, equipment matures and resource prices fluctuate, which brings forth pricing as an additional cause for uncertainty.

A final set of uncertainties that are introduced are parameters influencing operations and primarily the cost of personnel. Examples are the amount of yearly calls to the helpdesk per user, the average duration of such a call, wages, etc...

Now that these uncertainties are introduced, the model is rerun a few thousand times and the probability distributions of the output variables are estimated. To support the conclusion that crowdsourcing significantly reduces TCO the probability distribution of the percentage difference between the traditional and crowdsourced approach is used. Figure 4 captures this function. It clearly shows that even under the most negative scenarios the difference is still more than 30% which is strongly in favour of the initial conclusion.

Figure 5 shows the distribution of the project's NPV for a crowdsourced rollout using indoor BSs. The NPV measure is a good indicator of the financial feasibility and profitability of the case and its distribution can be used to analyze the robustness of the second conclusion: that a positive business case can be found for the city of Ghent. The chart illustrates that in about 10% of the sample the project isn't profitable. Taking into account that the input distributions were modelled rather pessimistically this still gives a general positive outlook on the case and underlines the findings of section IV. Nevertheless this is still a considerable risk that prompts the authors to look further in the causes of the uncertainty. A sensitivity analysis which identifies the important determinants of uncertainty can be a helpful addition to the uncertainty analysis in this research setting.

This sensitivity analysis is captured by figures 6 and 7. They list the first order sensitivty indices, normalized to 1, of the 5 most important determinants of uncertainty of NPV and TCO respectively.

The first order sensitivity index is a variance based sensitivity index that captures the variance that would be removed from the model by fixing a certain input parameter. The higher the index the more variance that would be removed. This measure is thus an indicator for prioritizing research, it shows for which variables the input uncertainty reduction that follows research would lead to the biggest reduction in model uncertainty.

$$\mathbf{E}[\mathbf{V}(Y|X_i)] + \mathbf{V}[\mathbf{E}(Y|X_i)] = \mathbf{V}(Y) \quad (2)$$

$$\frac{\mathbf{V}[\mathbf{E}(Y|X_i)]}{\mathbf{V}(Y)} = S_i \quad (3)$$

If one looks at these charts one can see the importance of an accurate dimensioning of the BSs as well as an accurate prediction of adoption and ARPU. These insights prompt the performance of future research efforts in this direction. For this particular project this will lead to the addition of a Geographic Information System (GIS) based dimensioning tool to the model. This tool is currently being developed by the technical partners in the GreenWeCan project. As to the

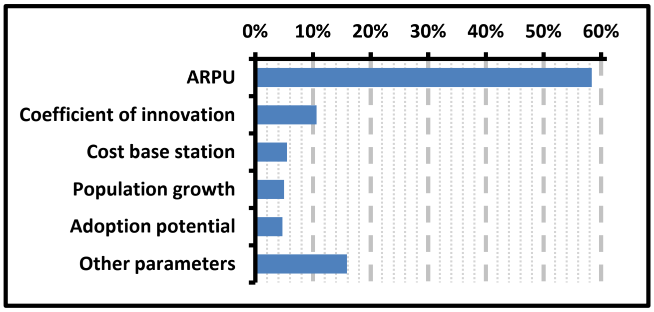

Fig. 6. First order sensitivity indices for NPV

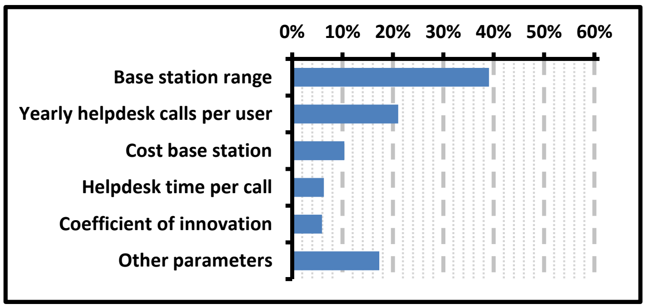

Fig. 7. First order sensitivity indices for TCO

adoption potential analysis, the methodology described in [13] will be further developed and applied to wireless cases as well.

VI. Conclusions & Future Work

This paper analyzes the business case of a municipal Wi-Fi network in light of "Crowdsourced Wi-Fi" or "Wi-Fi Sharing" and shows that this strategy can significantly reduce the project's TCO; by even more than 50%. The prime reason for this conclusion is found to be the difference in equipment cost per square kilometer of the covered area.

The paper further illustrates that the overall business case of a crowdsourced Wi-Fi network has a likely positive outcome. The ARPU requirements for a profitable case are calculated and found to be reallistically achievable in relation to the tourism sector in Ghent. The example of a parking sensor rollout shows that taking into account indirect effects such as reduced backhauling cost of city owned infrastructure, can even ameliorate this business case.

The robustness of the results is tested using uncertainty and sensitivity analysis and deemed to be convincing. The sensitivity analysis further underlines the importance of adoption forecasting data and accurate network dimensioning, providing useful insights to channel future research such as the inclusion of GIS data to the model as well as CTI based adoption estimates.

Overall, the conclusion can be made that it is preferable for municipalities and researchers alike to look further into the legal and other institutional aspects of Wi-Fi sharing considering that from a financial perspective there is a distinct possibility for a beneficial case.

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