Path Selection Using Handover in Mobile Networks with Cloud-enabled Small Cells

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***Abstract*—To overcome latency constrain of common mobile cloud computing, computing capabilities can be integrated into a base station in mobile networks. This exploitation of convergence of mobile networks and cloud computing enables to take advantage of proximity between a user equipment (UE) and its serving station to lower latency and to avoid backhaul overloading due to cloud computing services. This concept of cloud-enabled small cells is known as small cell cloud (SCC). In this paper, we propose algorithm for selection of path between the UE and the cell, which performs computing for this particular UE. As a path selection metrics we consider transmission delay and energy consumed for transmission of offloaded data. The path selection considering both metrics is formulated as Markov Decision Process. Comparing to a conventional delivery of data to the computing small cells, the proposed algorithm enables to reduce the delay by 9% and to increase users' satisfaction with experienced delay by 6.5%.**

Keywords*— *small cells; mobile cloud computing; path selection; energy efficiency; LTE

I. Introduction

As demands of mobile users being shifted from hardware to software [1], opportunity for offloading computation from user equipment (UE) into cloud is becoming interesting possibility to provide enough computing power for even computationally demanding applications while saving battery of the UEs. However, conventional cloud computing approaches lead to a significant delay in delivery of offloaded data from the UE to a computing machine and back [2]. Therefore, delay sensitive applications cannot be widely used in this scenario. As a solution to overcome the problem of delay in mobile cloud computing, cloud resources should be deployed closer to the users. In common cellular networks, the closest place for deployment of computing resources is a base station. With increasing density of deployed cells, the small cells are seen as a mean to provide cloud computing services to users in proximity. This concept is known as Small Cell Cloud (SCC) [3]. In the SCC, the small cells (SCeNB) are empowered by additional computing and storage resources in order to enable efficient exploitation of delay sensitive and computation demanding applications, such as augmented reality or virus scanning To satisfy even high demands of the UEs on computation, the computing power distributed over nearby cloud-enhanced SCeNBs can be virtually merged together under one Virtual Machine (VM). The application is then offloaded from the UE to the SCeNBs if it is profitable from energy or delay point of view [4]. The VMs are deployed at SCeNBs with respect to their communication and computation capabilities. After selection of the SCeNBs, which take care of computation, data must be delivered to these cells [5]. Typically, the small cells are usually connected to backhaul, which is of a lower quality than backhaul of macrocells. Hence, distribution of data for computation from the cell providing radio access (serving cell) to all computing cells through backhaul of limited capacity can lead to significant delay. To that end, it is efficient to deliver data to selected computing cells not only through the serving cell but also by means of neighboring cells provided that those are in the user's radio communication range.

If we consider possible handover during transmission of data for computation, selection of the most appropriate way for data delivery to the computing cells becomes problem analogical to routing in Wireless Sensor Networks (WSN). Thus the WSN routing protocols may provide an inspiration how to treat the path selection in the SCC. Of course, mobile network topology does not enable such freedom as conventional WSN but it rather follows hierarchical network structure in WSN where some nodes are selected as gateways (cluster heads), which relay data to a target destination [6]. In our network, the SCeNBs can be seen as the gateway nodes. Each gateway has a fix number of options how to distribute offloaded computation data to the computing cells through fixe infrastructure of mobile network. This infrastructure is represented typically by a wired backhaul and core network of the operator. Therefore, the problem consists in selection of proper gateway (serving cell) for individual parts of offloaded data. The selected gateway must minimize data transmission delay and energy consumed by the UEs for the transmission. Note that the same problem can be defined also for delivery of computation results back to the UE (e.g., if the original path is not efficient due to user's movement). In this case, energy consumption on the side of SCeNB is not such limiting factor as the SCeNBs are not powered by short life-time batteries.

In WSN, plenty of algorithms have been defined. Basic routing algorithms for WSN do not consider energy consumption of data delivery or dynamic path update [6]. In the SCC, the energy is limiting only for radio communication between the UE and the SCeNBs. Also, dynamicity of the system is inherent feature of mobile networks. Therefore, energy as well as dynamicity must be taken into account. The dynamicity of scenario for WSN is addressed by Ad-hoc On-demand Multipath Distance Vector with Dynamic Path Update (AOMDV-DPU) [7]. Additionally to hop count metric, the algorithm selects paths based on Received Strength Signal Indicator (RSSI). However, even selection of paths with good RSSI to avoid weak radio links does not guarantee minimal delay. In addition, the AOMDV-DPU does not consider transmission energy, which is essential in our case. Similar weakness prevents implementation of Adaptive Multi-metric Ad-Hoc On-Demand Multipath Distance Vector Routing algorithm [8] to the SCC since it routes data based on RSSI, latency and node occupancy. Moreover, backhaul from the serving cell to the operator's core network is typically wired. In addition, if the serving cell selection is based on RSSI, the same path to the core network would be selected all the time disregarding selected SCeNBs for computation and backhaul status. Hence, WSN-like approaches cannot be easily applied to our problem.

Designed path selection algorithm should take into account UE's limited energy resources, radio and backhaul conditions, and UE's requirements on maximal possible delay for data delivery to guarantee Quality of Service (QoS). In existing approaches used for the SCC, the data to the computing cells is always delivered through the serving cell [3][5]. It means the UE is attached still to the same cell during delivery of all data. Then, the serving cell distributes data through operator's core network to the computing cells. This approach can be efficient if both radio channel between the UE and its serving cell as well as backhaul connection of the serving and all computing cells are of a sufficient throughput. Otherwise, limitation at any part of the communication chain leads to a degradation of the overall delay of computation offloading.

The contribution of our paper consists in design of path selection algorithm for the SCC environment. The proposed algorithm exploits possibility of handover to shorten the time of transfer of data for computation by avoiding usage of low capacity backhaul. The proposed scheme forces the UE to perform handover if it leads to shortening of data transfer time. To prevent wasting of energy at the UE side, the UE's energy consumption is also considered for path selection. The problem is formulated as a Markov Decision Process where handover is awarded by a reward depending on its impact on the energy consumption and delay.

The rest of this paper is organized as follows. In the next section, we define model of the investigated SCC system. In Section III, the proposed algorithm for path selection is described. Simulation environment and results are presented in Section IV. The last section summarizes major conclusions and outlines plans for future extension of this work.

II. SYSTEM MODEL

In this section, the model of the SCC is presented in order to enable description of the path selection algorithm.

We assume the system is composed of S SCeNB and U UEs. For each UE, the serving cell is selected as the SCeNB with the highest RSSI. As the UE moves, the serving cell is updated if the RSSI from the target SCeNB ($RSSI_T$) is higher than the RSSI of the serving cell ($RSSI_S$) plus handover hysteresis (Δ_{HM}), i.e., if $RSSI_T > RSSI_S + \Delta_{HM}$.

For each computation offloading request, the maximal delay of data delivery from the UE to the computing cells, T_{req}, is specified. This delay can be derived as a difference between maximum delay required by the UE for delivery of the computation results back to the UE (T_{max}) and the time required for computation of the offloaded task (T_{comp}); $T_{req} = T_{max} - T_{comp}$. Parameters T_{max} and T_{comp} are related to application and available computing capacity of cloud-enabled SCeNBs, respectively. For our purposes, specific way of T_{max} and T_{comp} derivation is not relevant; we just need to know the time constraint remaining for data transmission.

The set of SCeNBs selected for computation is denoted as a Y. Each cell is expected to compute a part $\lambda_n \epsilon (0,1]$ of the whole offloaded task. The whole task is of the overall size of L_{UE}. The individual part L_n computed by the $SCeNB_n$ is then expressed as $L_n = \lambda_n \cdot L_{UE}$ with $\sum \lambda_n = 1$. In this paper, we assume each task is split into parts of the same size i.e. $\lambda_1 = \lambda_2 = \ldots = \lambda_n$.

As shown in Fig. 1, data from the UE to the $SCeNB_i$ is transferred over radio link with capacity c_i^R. Further, the $SCeNB_i$ is connected to the operator's core with a backhaul (typically ADSL or optical fiber) of capacity c_i^B. Note that the backhaul is not utilized if the serving cell is also sole computing cell. Data is then processed by the $SCeNB_i$ or forwarded to another computing $SCeNB_x$ through backhaul of the $SCeNB_i$ (with capacity c_i^B in uplink) and backhaul of the computing cell $SCeNB_x$ (with capacity c_x^B in downlink). Note that index x stands for any SCeNB out of S except the $SCeNB_i$. After cells perform data computation, the results are delivered back to the UE. A new path for backward data delivery (from the $SCeNB_x$ to the UE) can be derived if radio and backhaul links are not symmetric in uplink and downlink, if the UE moves during computation or if the radio channel and backhaul link load or quality change. Otherwise, the same path can be reused.

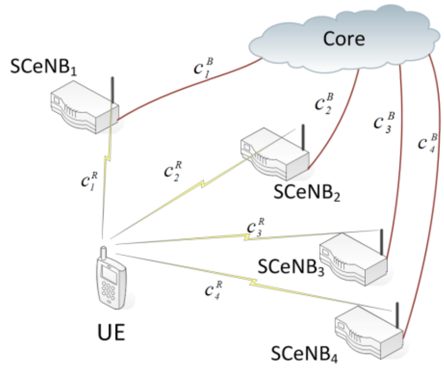


Fig. 1. Model of the SCC system for path selection.

To avoid an increase in energy consumption at the UE, we model energy E as the power consumed by the UE for data transmission over a transmission time. The energy consumption depends on Modulation and Coding Scheme (MCS) and available bandwidth represented by Resource Blocks (RBs) in LTE-A system. The MCS is a function of Signal to Interference plus Noise Ratio (SINR) observed at receiver. The SINR at receiver is proportional to the transmission power P_{Tx} at transmitter, path loss and interference from other cells. In LTE-A, the P_{Tx} required for selected MCS and given number of allocated RBs is defined, according to 3GPP [9] and [10], as follows:

$$P_{Tx} = \min(P_{MAX}, P_0 + \alpha \cdot PL + 10\log_{10}(M) + \Delta_{TF} + f) \qquad (1)$$

where P_{MAX} is the maximum available transmission power (23 dBm for the UE class 3 [11]); $\alpha \epsilon \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$ corresponds to the path loss compensation factor, PL is the downlink path loss estimate; M stands for the number of assigned Resource Blocks (RBs); Δ_{TF} represents a closed loop UE specific parameter, which is based on the applied MCS; and f is a correction value also referred to as a TPC command (for more details on Δ_{TF} and f, see [10]); and parameter P_0 represents the power offset computed as: $P_0 = \alpha \cdot (SINR_o + P_N) + (1-\alpha) \cdot (P_{MAX} - 10\log_{10}(M_0))$; where P_N is the noise power per RB, and M_0 defines the number of RBs, which would be allocated to the UE if the cell would transmit with maximum power.

Parameters Δ_{TF} and f are used for dynamic adjustment of the transmission power to keep required SINR at the receiver. As we use open loop power control, we can omit these parameters as indicated in [12]. The parameter α is set to 1 so the UE fully compensates the path loss. Under these assumptions, we can simplify the power offset to $P_0 = \alpha \cdot (SINR_o + P_N)$. Then, (1) can be rewritten as:

$$P_{Tx} = \min(P_{MAX}, \alpha \cdot (SINR + P_N + PL) + 10\log_{10}(M)) \qquad (2)$$

The energy consumed by transmission of data over the radio channel is derived, according to [13], as:

$$E = P_{Tx} \cdot T_R \qquad (3)$$

An example of tradeoff between energy and duration of transmission of 100 kB using 10 RBs with PL=80 dB is shown in Fig. 2. As this figure shows, high energy is consumed if the transmission lasts a short time. Contrary, less energy is required if the transmission time is prolonged.

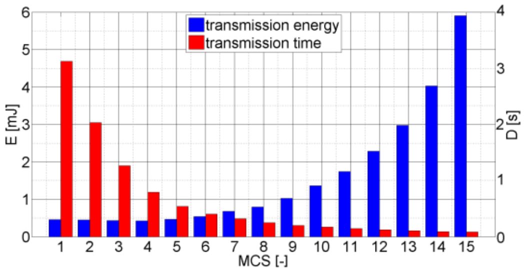


Fig. 2. Example of tradeoff between energy and time consumed by transmission of 100 kB using 10 RBs with path loss of 80 dB.

III. Proposed Path Selection Algorithm for SCC

In this section, we describe the proposed path selection algorithm and then its complexity is analyzed.

A. Path selection algorithm

In existing approaches, only path from the user to the computing cell through the serving cell is used [3][5]. To overcome potential delay due to backhaul of limited throughput, we consider opportunity to use also neighboring cells and deliver individual parts of the data for computation to the specific computing cells through the cells, which offers low delay of the transmission over both radio and backhaul. Note that for each computing cell, data can be delivered through different serving cell.

The path selection algorithm suitable for our problem combines cost of data transmission over wired and wireless links with energy consumed by the UE for transmission over the radio in order to satisfy delay constraint T_{req}. Therefore, any delay higher than the required one is considered as unsuitable. If at least one available path fulfills T_{req}, all paths with delay exceeding T_{req} are dropped and are not considered in the path selection. If no path is able to provide delay lower than T_{req}, the path with the lowest delay is selected.

The path selection is based on weighting of path delay (D) and energy (E) consumed by UE's transmission over the radio part of the path. In order to weight both metrics we normalize their values as follows:

$$D_i^N = \frac{D_i}{max(D_1, D_2, \ldots, D_p)}; \quad E_i^N = \frac{E_i}{max(E_1, E_2, \ldots, E_p)} \qquad (4)$$

where D_i (E_i) is the delay (energy) of the i-th path and p is the number of possible paths from the UE to the computing cell.

The path selection is then defined as Markov Decision Process, which calculates reward (penalty) of transition from the current state s to one of possible future states s'[14]:

$$\begin{aligned} V_\pi^k(s) &= Est\left[\sum_k R^t \mid \pi, s\right] = \\ &= R(s) + \sum_k T(s, \pi(s,k), s') \cdot V_\pi^{k-1}(s') \end{aligned} \qquad (5)$$

The current state s represents currently selected path (using the serving cell) and the future state s' represents another possible path including all combinations of radio and backhaul connections. Hence, the estimate (Est) represents possible outcome of reward by performing handover to different cell. The Est is computed over k steps, representing duration of the data transmission. Label π stands for the policy, which defines what action should be taken in step s to maximize total reward. Total reward for transition from the state s to s' consists of two parts. The first one, $R(s)$, denotes immediate reward for transition from the state s. The second part, summation, represents expected future payoff as a sum over k steps. In our case, π obtained at the end of the algorithm provides desired policy maximizing the reward. The reward depends on the delay due to handover if the handover is performed (T_H), delay by the transmission over radio (T_R) and delay on backhaul (T_B). Thus, the reward for transition from the state s to the s' is written as:

$$\begin{aligned} & V_\pi^k[(s,s')] = \\ & \gamma\{k[E[T_R(s')] - E[T_R(s)]] + E[T_H(s,s')]\} + \\ & + (1-\gamma)\{T_H(s,s') + k[T_R(s') - T_R(s)] + k[T_B(s') - T_B(s)]\} \end{aligned} \qquad (6)$$

where γ is the weighting factor showing preference for low delay ($\gamma=0$) or for high energy efficiency ($\gamma=1$); $E[T_R]$ denotes energy consumed by UE's radio communication through the serving cell (state s) or another neighboring cell (state s'); and $E[T_H(s,s')]$ stands for the energy consumed by handover from the serving to the neighboring cell (from state s to state s').

The transmission delays T_R and T_B are computed knowing amount of data to be transferred over radio (n_{bits}^R) and particular backhaul (n_{bits}^B) and knowing capacity of radio link (c_i^R), capacity of backhauls of the serving cell (c_i^B) and the computing cell (c_x^B):

$$T_R = \frac{n_{bits}^R}{c_i^R}; \quad T_B = \frac{n_{bits}^B}{c_i^B + c_x^B} \tag{7}$$

B. Algorithm complexity

Complexity of the path selection algorithm is proportional to the number of computing SCeNBs (n) and the number of SCeNBs in proximity of the UE (m). The SCeNBs in proximity of the UE are selected according to the SINR. The number of possible paths can be computed as partial permutation. Thus, the complexity of the proposed path selection algorithm is $O(m^n)$.

IV. PERFORMANCE EVALUATION

In this section, models and scenario for performance evaluation are defined. The evaluation is carried out by means of simulations in MATLAB.

A. Simulation sceanrio and models

Major parameters of the simulation, presented in TABLE I, are in line with recommendations for networks with small cells as defined by 3GPP in [15]. We also follow parameters of the physical layer and frame structure for LTE-A mobile networks defined in the same document.

Signal propagation is modeled according to 3GPP [15]. We consider wall loss as listed in TABLE I. Based on the path loss, the throughput of UE is derived using a mapping function for SINR and MCS obtained from [16] with block error rate of 10 %. The MCS is then used for computation of radio link capacity. For this we assume allocation of 10 RBs for each user demanding the SCC services. Furthermore, we assume 20 RBs are consumed by background traffic generated by users not exploiting the SCC. The backhaul is modeled as DSL and optical fiber links. For DSL, the mean value of capacity (μ) is set to 1 and 5 Mbps for uplink and downlink, respectively. In case of optical fiber, the mean capacity is equal to 100 Mbps for both uplink and downlink. For each SCeNB, the capacity of backhaul is selected randomly between $\mu/2$ and $1 + (\mu/2)$.

To model behavior of heavily loaded system, the requests for commutation offloading are generated by UEs immediately after previous one is completed. This case is the most challenging due to limited capacity of backhaul and radio. Each request corresponds to the generated traffic of 300 kB and 30 MB. The offloaded data is computed at 2, 3 or 4 cells, with equal probability of each option. One of the computing cells is always the serving one as suggested in [5].

All UEs are moving within an area composed of two-stripes of buildings [15]. Size of each block of buildings is 20x100m and blocks are separated by streets with width of 10m. The overall area is composed of 4x4 blocks (i.e., size of the whole simulated area is 560x130m). Fifty outdoor UEs are randomly deployed at the beginning of the simulation and then they move along the streets according to Manhattan Mobility model with speed of 1 m/s. Inside buildings, the SCeNBs are randomly dropped to the apartments with equal probability in a way that 20% of apartments are equipped with a SCeNB. Therefore, 80 UEs and 80 SCeNBs are deployed indoor. Movement of the indoor UEs is modeled according to [17], i.e., the UEs move within an apartment at discrete positions. Besides small cells, also a macrocell is placed outside the area with the two stripes buildings at coordinates of [200m, 200m].

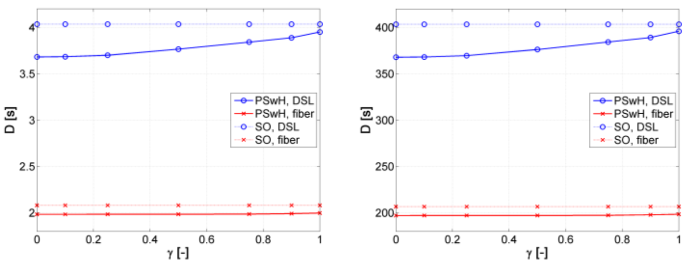
TABLE I. SIMULATION PARAMETERS.

Parameter	Value
Simulation area	560m x 130m
Carrier frequency	2000 MHz
Tx power of eNB/SCeNB [dBm]	43 / 23
Attenuation of external/internal/separating walls	20/3/7 dB
SCeNB deployment ratio	0.2
Shadowing factor	6 dB
Handover interruption duration	30 ms
Number of Indoor/Outdoor UEs	80/50
Speed of outdoor users	1 m/s
DSL backhaul mean throughput UL/DL	1/5 Mbit/s
Optical fiber backhaul mean throughput UL/DL	100/100 Mbit/s
Traffic generated by one request	300 kB/30 MB
Simulation time/Number of simulation drops	5 000 s / 10 drops

B. Simulation results

In our simulations, we compare the proposed path selection with handovers (PSwH) with conventional algorithm, which transfers data to all computing SCeNBs through the serving SCeNB [3][5]. In this paper we denote this common algorithm as the Serving Only (SO). To compare results we show mean D and E spent by data transmission over the selected path using the SO and the proposed PSwH.

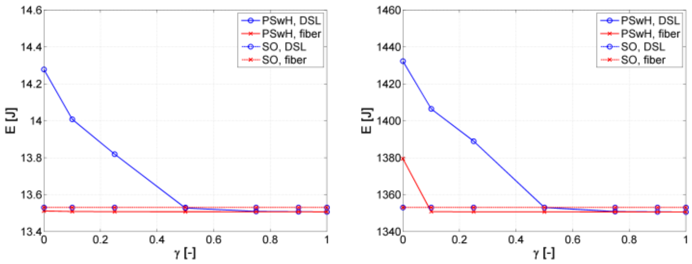
Impact of the proposed PSwH algorithm on average duration of the offloaded data transmission between the UE and computing SCeNBs (denoted as delay) is depicted in Fig. 3. As can be seen, the delay is shortened more significantly for backhaul with limited capacity (DSL). For DSL, the proposed PSwH reduces delay between 9% if delay criterion is preferred ($\gamma = 0$) and 2% if energy consumption is more important ($\gamma = 1$). This ratio is nearly independent on the amount of data to be transferred per request for computation offloading (300 kB in Fig. 3a and 30 MB in Fig. 3b). If the backhaul of higher capacity is considered (in our case, optical fiber), the gain is lower (4.7% and 4.0% for $\gamma = 0$ and $\gamma = 1$, respectively) because this backhaul is able to forward data to the computing cell in a shorter time and handover is not efficient in this case.



(a) (b)

Fig. 3. Average delay D required for transmission of offloaded computing task to computing cells for request size of 300 kB (a) and 30 MB (b).

The proposed PSwH should avoid dramatic draining of the UE's battery due to handover. In Fig. 4, we can see that the energy consumption of the PSwH is similar as for the SO if optical fiber is used for backhaul and if each request is of 300 kB (PSwH reduces E by 0.2%). If the amount of transmitted data is increased to 30 MB, the energy consumption is slightly increased by the PSwH (by 1.9%) if delay is preferred ($\gamma = 0$). However, for $\gamma \geq 0.1$, the energy consumption of both algorithms is roughly the same for optical fiber backhaul (the PSwH even outperforms the SO by 0.2%). For DSL backhaul, the PSwH requires more energy comparing to the SO for low γ (approximately 5.5% if $\gamma = 0$). This is due to selection of worse radio channel, which is less energy efficient, in order to avoid backhaul with limited capacity. Nevertheless, by setting $\gamma = 0.5$, energy consumption of the PSwH is again the same as for the SO.



(a) (b)

Fig. 4. Average energy E consumed by radio transmission of offloaded computing task to computing cells for request size of 300kB (a) and 30 MB (b).

From above discussion, we can conclude that the PSwH enables to reduce delay by 9% and 4.7% if $\gamma = 0$ for DSL and optical fiber backhauls, respectively. This is at the cost of higher energy consumption (increased by 5.5% for DSL and 1.9% for optical fiber). However, by setting $\gamma = 0.5$ for the PSwH if DSL is used, the delay can be shortened by 6.7% even if the energy consumption is also reduced by 0.2%. For optical fiber backhaul, the most efficient is to set $\gamma = 0.1$, which results in shortening the delay by 4.7% and the energy consumption reduction by 0.2%.

The satisfaction of UEs using the PSwH and SO algorithms is shown in Fig. 5 (offloading of 300 kB) and Fig. 6 (offloading of 30 MB). The satisfaction is understood as the ratio of users, whose experienced delay is not higher than the requested one (i.e., $D \leq T_{req}$). As can be seen from Fig. 5 and Fig. 6, the UEs' satisfaction is increasing with T_{req} for both algorithms. This fact can be expected because more time is available for delivery of data if a higher T_{req} is enabled. Comparing the PSwH with the SO, the proposed algorithm increases the satisfaction up to 6.5% for DSL backhaul and for both amounts of offloaded data (300 kB as well as 30 MB). The satisfaction increases as γ decreases because priority is on delay in this case while energy is less important. For optical fiber backhaul, the PSwH improves the satisfaction by 2.8% and by 1.8% for requests of a size of 300 kB and 30 MB, respectively. The lower improvement in satisfaction for optical fiber backhaul and lower size of offloaded data is due to the fact that high capacity backhaul can easily transfer requests of small size from the serving cell to the computing cells and handover to computing cells is not necessary.

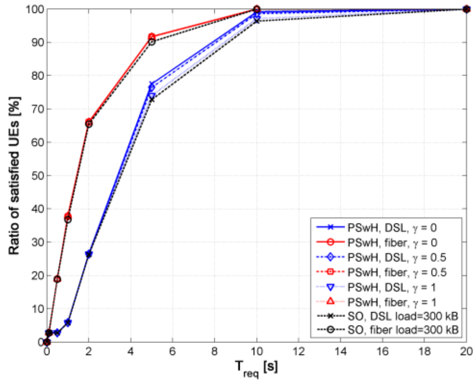


Fig. 5. Satisfaction of users with experienced delay for request size of 300 kB.

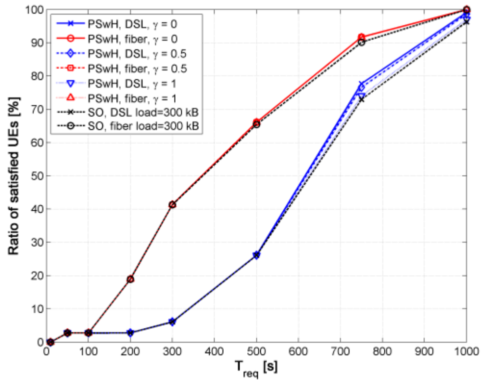


Fig. 6. Satisfaction of users with experienced delay for request size of 30 MB.

The proposed algorithm introduces additional handovers, which can lead to handover interruption and redundant signaling. The first problem, handover interruption, is not related to the SCC services as the users do not care about interruption in data transmission, they insists on the overall delay of computing results delivery. Impact of the handover interruption on the overall delay is considered in the PSwH (see (6)), thus, all results already considers this issue. In case of multiple applications running at the same UE, priority of other application with respect to the offloaded application must be considered.

For analysis of impact of handover on the signaling overhead, average increase in amount of handovers performed by users is shown in Fig. 7. From this figure, we can observe that the number of additional handovers is higher for DSL backhaul if priority is set to experience low delay ($\gamma = 0$). With respect to usage of the SO algorithm, additional 20% of handovers are performed. In this case, transferring data over backhaul with low capacity requires more time and, consequently, it is more difficult to meet T_{req}. Therefore, handover to a computing cell is performed more often as the UE can use radio of a higher quality instead of a low quality backhaul for data transfer. Nevertheless, with preference for low energy consumption ($\gamma = 1$), the users stick to the serving cell providing mostly the highest channel quality, which is the most energy efficient. In this case, increase of only 7% in the number of handovers is observed.

For optical fiber backhaul, the number of additional handovers converges to 7% with $\gamma = 1$ for both sizes of request. Nevertheless, for $\gamma = 0$, the request of small size (300 kB) is transferred over backhaul so promptly that the time consumed by handover itself is more significant. Hence, handover is performed less often.

Generated overhead due to handover is in order of kb per handover event [18]. Consequently, considering the results presented in Fig. 7, we can conclude that increasing number of handover by 20% leads to negligible additional signaling overhead due to handover management.

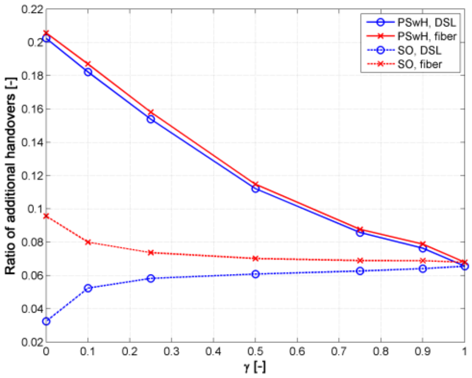


Fig. 7. Ratio of additional handovers due to proposed algorithm (PSwH) with respect to usage of serving cell only (SO).

V. Conclusion

In this paper, we have proposed a new algorithm for selection of the path from the UE to the cloud-enhanced small cells. The proposed algorithm forces handover to the computing cell if it is efficient by means of the overall transmission delay considering radio and backhaul or energy.

The proposed algorithm is efficient especially for capacity limited backhauls (e.g., DSL). In this case, it reduces transmission delay by 9% if the UE's energy consumption is of lower preference and an increase in the energy spent for transmission by 5.5% is tolerable. If energy consumption is a constraint, the proposed algorithm still reduces transmission delay by 6.7% while the energy required for transmission is at the same level as for the conventional approach. For backhaul of high capacity (such as optical fiber), the delay can be reduced by 4.7% while energy consumption is not raised. In addition, the user's satisfaction with experienced delay is increased by up to 6.5% and 1.8% for DSL and optical fiber backhauls, respectively.

In the future, we will focus on extension of the proposed algorithm to scenario with over-the-air communication and to combination with possible migration of VMs among SCeNBs in order to shorten the delay.

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