

Raising Coverage and Capacity using Fixed Relays in a Realistic Scenario

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Abstract—Multihop techniques are known as a practical solution for covering huge radio cell areas when there are only very few base stations (BS). This is the case when fiber access is limited and BS CAPEX and OPEX are very expensive. For WiMAX and 3GPP-LTE it is possible to operate relay stations which are only fed over the air link. While having some inherent overhead due to increased radio resource usage, there are nevertheless impressive gains in the coverage compared to a BS alone and also in the capacity of the whole radio cell. Near relay nodes (RN) there is not only better SINR to the user, which is obvious, but it is often more efficient to associate to a RN instead of the BS, taking into account all resources used for the first and second hop. Therefore this is a low cost measure to increase the system efficiency. This has been shown in the literature for artificial scenarios so far.

In this paper we study a realistic scenario using data from topology information and raytracing. The city of Jersey was taken as example. The data is analyzed numerically, with all layer-1 and layer-2 performance models specified analytically. We study the case of one base station only, one BS with four RNs, and the latter plus another ring of nine RNs. The BS has fiber access, while the first hop of Relays (H1) is fed over the air from BS and the second hop H2 is fed by the RNs of group H1. We present results for the gains in coverage and capacity that are obtained by these Multihop techniques.

Index Terms—Relaying, Multihop, LTE, Coverage, Capacity

I. INTRODUCTION

REALISTIC scenarios have not been analyzed so far for the use of fixed relay nodes in future OFDMA-based transmission schemes like 3GPP-LTE [1] or WiMAX [2]. The benefit for the coverage and capacity in relay enhanced radio cells was shown in the past with free-space propagation or Manhattan Grid [3]. Other related work in this area mostly analyzes regular cellular geometries without considering realistic pathloss due to obstructions [4]–[6]. In this paper we build upon 3D models of the city of Jersey [7] with raytracing tools [8], study the scenario for 2D and scalar performance measures and extend the analysis for realistic areas around the BS. Compared to abstract and regular cellular scenarios [9], this provides a good proof-of-concept.

The benefit of Multihop is the cost-efficient provisioning of radio access over the area, no matter if the BS is in line-of-sight or not. Using RNs is viable at much lower cost than providing more base stations due to their need for high-rate fixed network access at every location. Due to the limited power of transmitters and the high path loss in non-line-of-sight conditions the received signal strength is not sufficient

in many urban areas. To improve the coverage therefore more sending stations are needed, which can be full BSs or relay nodes (RNs of store-and-forward type).

OFDMA-based transmission allows to coordinate radio resources in time and frequency domain. In any relay enhanced cell we assume a full coordination, so that there is no intra-cell interference. Therefore, a resource block can only be used by one of the actors, either BS or one of the four $RN_1 \in H1$ or one of the nine $RN_2 \in H2$. For this reason, any traffic PDU that goes from BS to a user terminal (UT) associated to RN_2 consumes three resource blocks R_0, R_1, R_2 , one on each hop 0, 1, 2. The size of R_i in bits shall be the same, but the size in terms of time and frequency bandwidth ($T \times F$) depends on the modulation&coding scheme (*PhyMode*) on this subchannel.

Close to the sender, the higher received SINR value allows the highest *PhyMode*, i.e. the highest data rate. At the cell border the offered data rate is one order of magnitude lower (QPSK – 1/3 compared to QAM64 – 5/6 for LTE [1]). A terminal operating at the lowest *PhyMode* occupies a ten times higher part of the spectrum than a terminal operating at the highest *PhyMode*. That means the average cell capacity is overproportionally determined by the maximum possible rate at the outer regions.

The paper is structured as follows. Section II defines the scenario. Next, the used layer 1 (PHY) and layer 2 (DLC) models are explained. Numerical results presented in the next section, which also provides 2D result maps of the area. The last section ends with a concluding summary.

II. SCENARIO DEFINITION

Jersey has been chosen for this scenario because the area of approx. 4.439 km^2 is a typical cell size. By using a radio network planning tool, base stations and all relay nodes are placed at best possible locations, see Fig. 1. The topology (building placement) was known in advance and raytracing tools have been used to obtain the received signal power $P_{R,i}$ at each location from each possible transmitter site. The determination of the BS and RN locations (above roof top) was performed iteratively with a radio planning and placement tool. The physical parameters and calculation steps are given in section III. In the end a coverage map was obtained which shows for each point on the map which serving station a terminal is best associated to (best server). This can be the base station, if this is the rate optimal association, but it can also be one of the relays $RN \in H1$ or $RN \in H2$. The maximum achievable rate at a certain point is then determined. From

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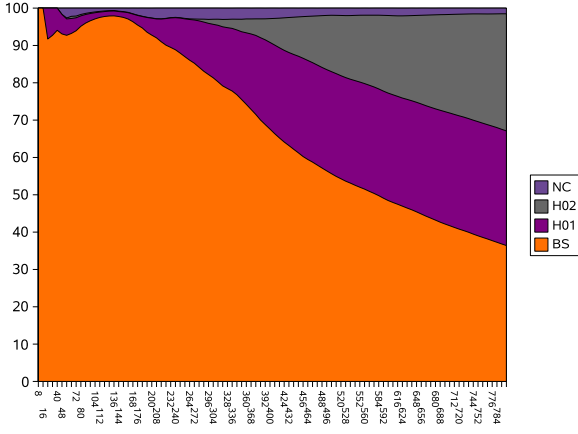


Fig. 4. The percentage of each station group used as a function of the cell radius from 0..800m

B. DLC layer

On DLC (MAC) layer, there is an overhead due to framing, signaling and ARQ retransmissions. The latter depends on PER , which can be taken into account when assuming selective repeat ARQ by equation 5.

$$r_{aboveARQ} = r_{belowARQ} \cdot (1 - PER) \quad (5)$$

In total we obtain a MAC overhead of $MAC/PHY = 132.3\%$. The PHY overhead of $PHY/RAW = 107.1\%$ comes from OFDM cyclic prefix duration. Under multihop operation there are individual resources needed on every hop. The constant packet length requires a different resource share depending on the used $PhyMode$ which determines the maximum rate $r_{i,max}$ usable on each hop. Therefore we can get the maximum rate on the second hop to be

$$r_2 = (r_{1,max}^{-1} + r_{2,max}^{-1})^{-1} \quad (6)$$

and on the third hop

$$r_3 = (r_{1,max}^{-1} + r_{2,max}^{-1} + r_{3,max}^{-1})^{-1} \quad (7)$$

For every location (x, y) we can now determine the best rate out of r_1, r_2, r_3 which gives us the result in Figure 7. One of the three rates is maximum and the index i of the maximum r_i determines the “best server”, i.e. it shows which station the UT at that location should be associated with.

The performance results have been obtained over different areas. First, the full area was used, including less densely populated parts (“square”). Second, a circular area with a radius of 800m around the BS was defined, which gives a realistic cell size (“circle”). Third, the area within a polygon (Fig. 1) was studied (the urban populated area).

IV. ANALYSIS RESULTS

The analysis has been carried out to generate the two-dimensional data in fig. 6 and 7. Scalar results were only counted in the polygon area defined in Fig. 1. Here we show the downlink only that also applies to the uplink if the uplink pathloss is the same (FDD). But the benefit in terms of capacity reveals if we derive scalar performance measures

Scenario	coverage [%]	capacity [Mbit/s]	spec. eff. [bit/s/Hz]
BS only	47.257	16.223	0.901
BS+H1	79.891	18.217	1.012
BS+H1+H2	98.519	21.583	1.199

TABLE II

SCALAR RESULTS FOR THE RELAY SCENARIO WITHIN THE SQUARE AREA

Scenario	coverage [%]	capacity [Mbit/s]	spec. eff. [bit/s/Hz]
BS only	64.816	18.519	1.029
BS+H1	87.536	22.091	1.227
BS+H1+H2	98.925	24.375	1.354

TABLE III

SCALAR RESULTS FOR THE RELAY SCENARIO WITHIN THE POLYGON AREA

from it. The coverage (in % of the area) of the scenarios differing by the number of relays involved is determined by counting all locations with $SINR > SINR_{min}$. For LTE $SINR_{min} = 0.9dB$ holds. Figure 3(a) shows the coverage of each scenario. The system capacity is determined by assuming equal traffic load for each user terminal and a homogeneous user density over the area. This means that a UT far outside, having a low $PhyMode$, requires more share of the resources than a UT close to the BS. The following equation [12] for the capacity C considers this:

$$\frac{1}{C} = \int_{polygonarea} \frac{1}{Capacity(x, y)} dx dy \quad (8)$$

Figure 3(b) shows the capacity of each scenario. Figure 5 shows that in a multihop scenario, more and more of the coverage area of BS is taken over by RNs . The capacity C in bit/s can be used to calculate the spectral efficiency $e = C/b$ using the used bandwidth b . The performance metrics are shown in Table II for the full area and in Table III for the densely populated polygon. According to this, two tiers of relays, compared to the BS only scenario, increase the coverage by a factor of 2.08 overall and 1.53 within the city, and both the capacity and spectral efficiency by a factor of approximately 1.33 both overall and within the city. Figure 4 shows the partition of area which is served by either BS, H1 or H2 dependent on the radius of the cell. We observe, that a first ring of relays comes in early, and a second ring is worth to use beginning from 350m. These numbers show the benefit of using relays. The radio power sum is of course more here, but the expensive fiber access to the BS is saved, which is the limitation in early rollout phases.

V. CONCLUSION

In this paper a realistic urban scenario was treated offering numeric results for the coverage and capacity of a multihop radio cell. We analyzed the topologic structure of the city to get the path loss, $SINR$ and data rate values for every location in that area. Next the coverage (in %) and capacity (in Mbit/s) as well as the spectral efficiency were derived from that, calculated for the whole system, but counted only within a bounded polygon area. Doing this analysis for three scenarios, one with a base station only, one with two hops (one tier of relays) and one with three hops (two tiers of relays),

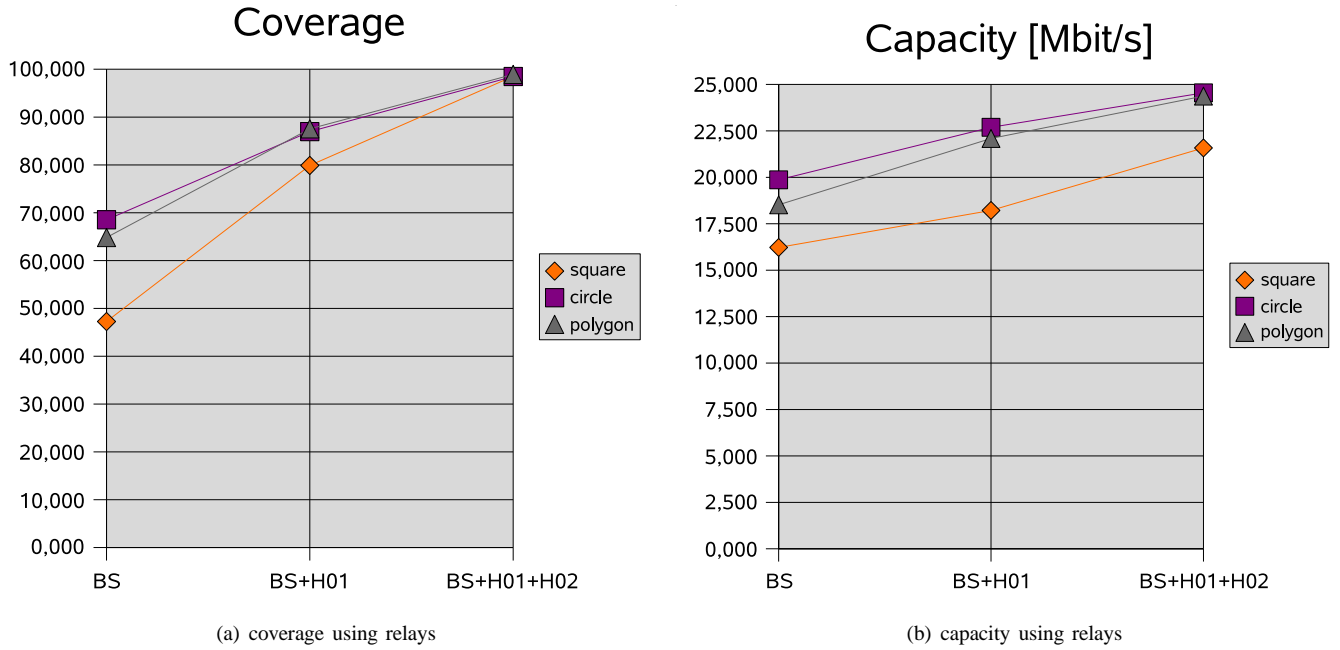


Fig. 3. Coverage and capacity compared for three scenarios: BS (one BS only), BS+H01 (with one tier of relays), BS+H01+H02 (BS with two relay hops H1+H2). Three different integration areas are the parameter.

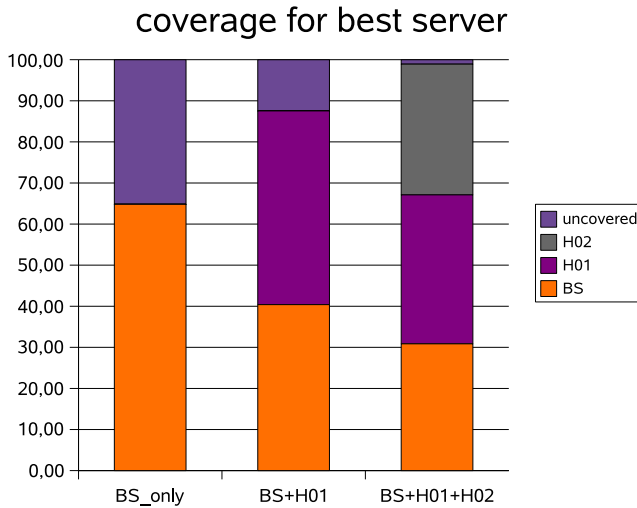
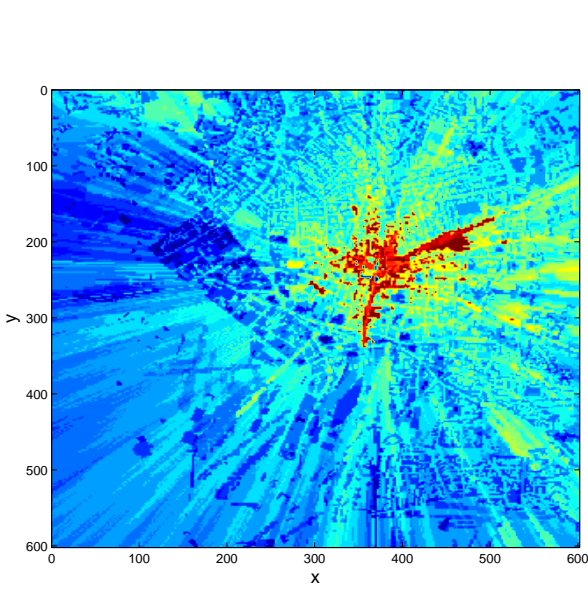
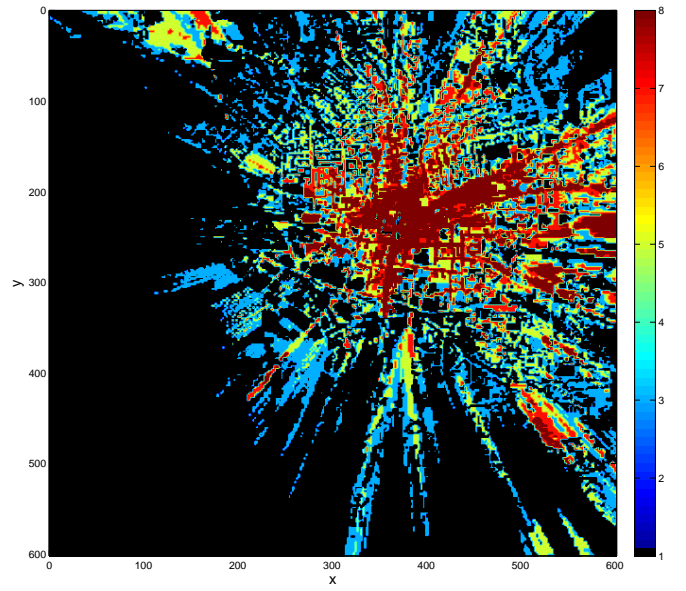


Fig. 5. The fraction of area served by each group of servers, determined within the polygon area

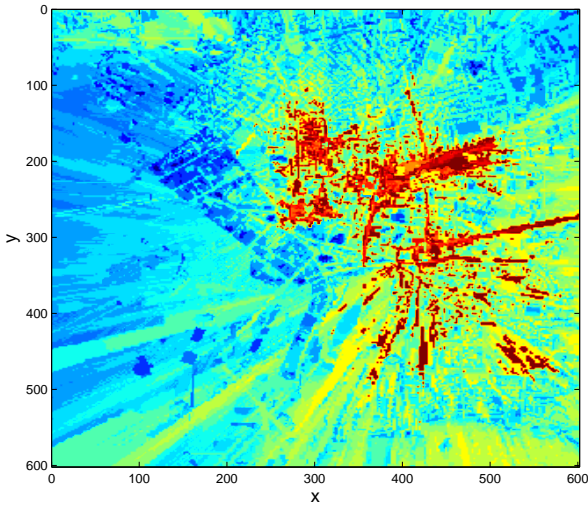
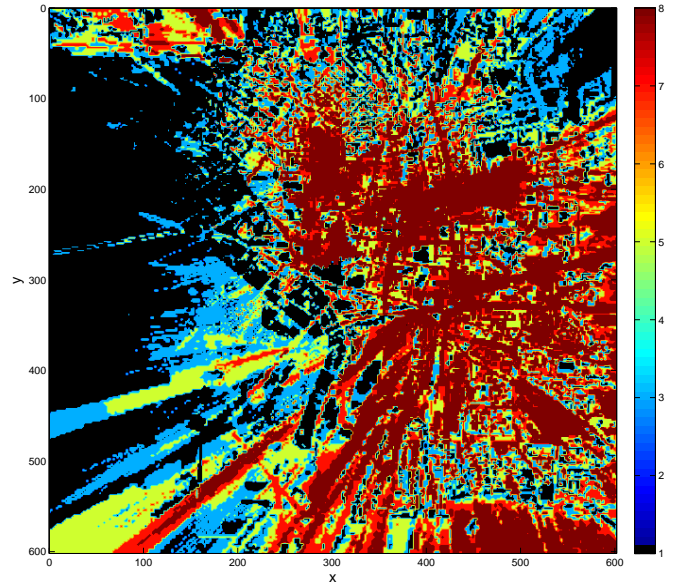
remarkable gains were visible when using relays. There is only one interface to the fixed network in all three scenarios. All the relays help to cover areas behind obstructions (buildings) where the path loss from the BS would be too large. The multihop techniques also improve the spectrum efficiency, because for all covered areas there is only one radio channel needed. The alternative was to place several BSs to serve the same area. But this requires more channels, since a cluster order of one suffers from too much interference. One outlook is an economic comparison of the CAPEX and OPEX related to the scenarios, e.g. [13]. Another outlook is the analysis of multiple cells with interference effects at the border.

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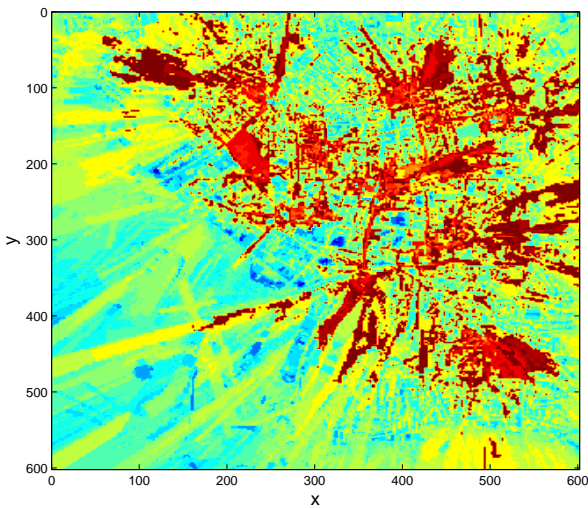
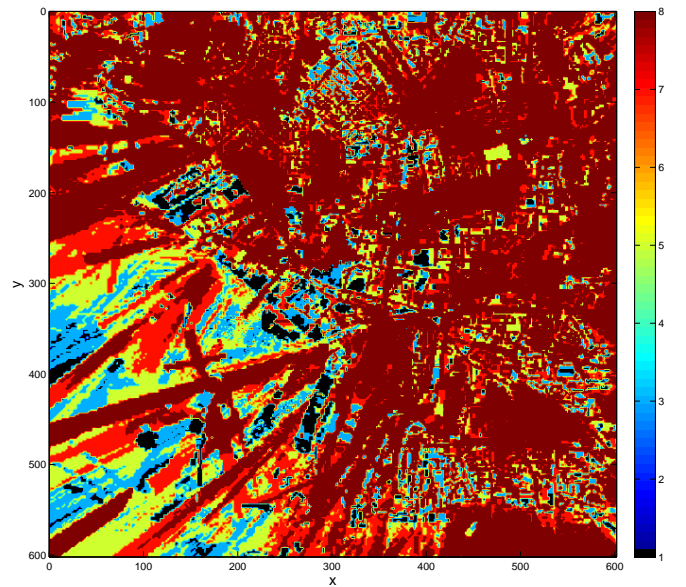
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(a) SINR of BS only (in dB)

(b) PhyMode of BS only

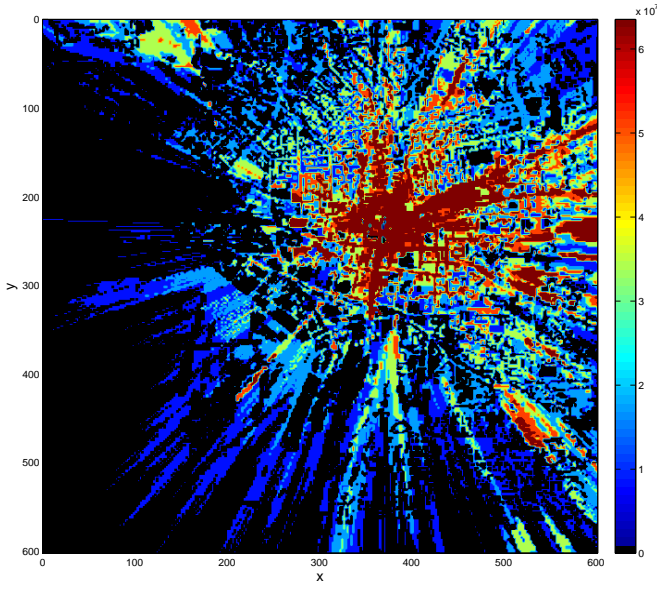
(c) SINR of BS with H1 (in dB)

(d) PhyMode of BS with H1

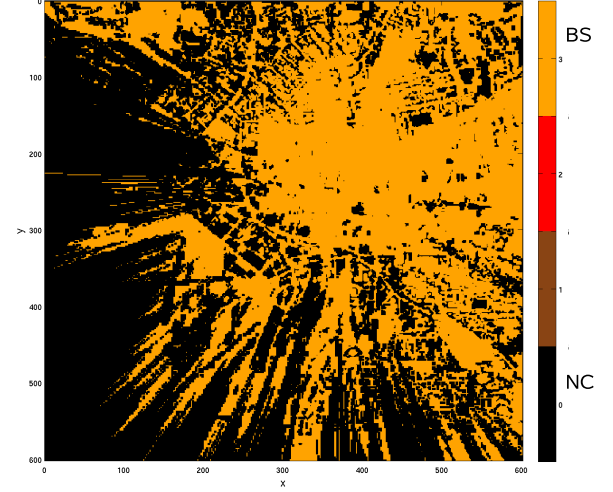
(e) SINR of BS with H1 and H2 (in dB)

(f) PhyMode of BS with H1 and H2

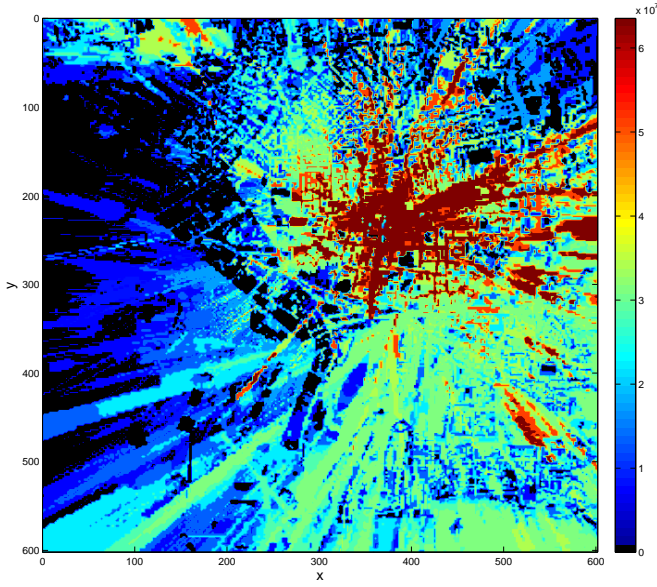
Fig. 6. On the area map of Jersey, these figures show the SINR [dB] and PhyMode [1..8] for a scenario with BS only, with one tier of relays H1, and with two relay hops H1+H2



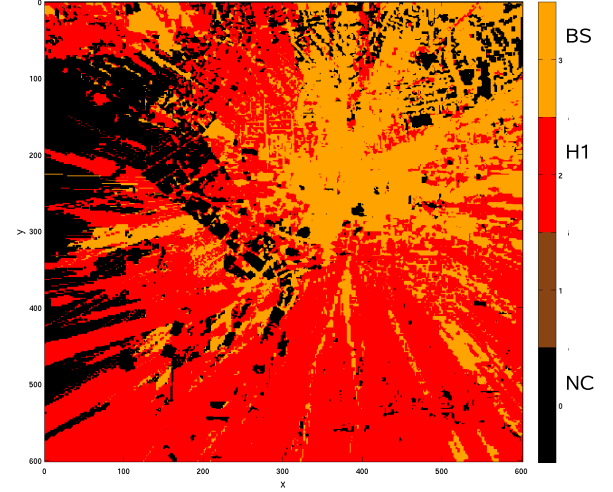
(a) Rate of BS only



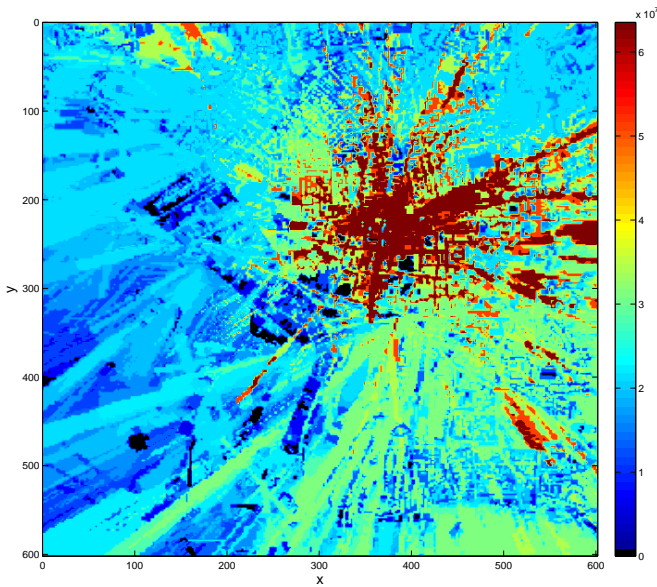
(b) Best server (coverage) of BS only



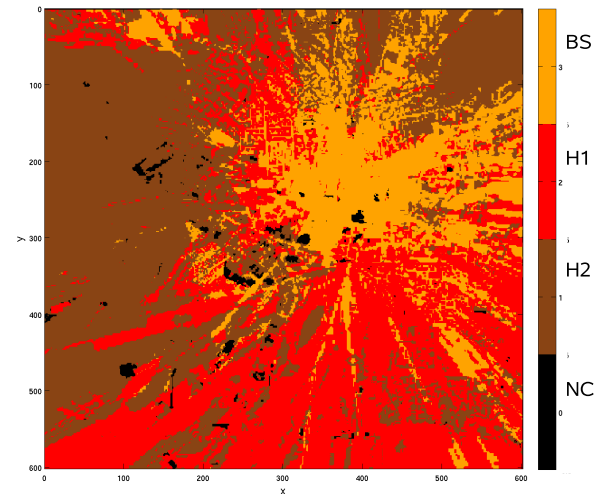
(c) Rate of BS with H1



(d) Best server (coverage) of BS with H1



(e) Rate of BS with H1 and H2



(f) Best server (coverage) BS with H1 and H2

Fig. 7. On the area map of Jersey, these figures show the available rate capacity [bit/s] and best server (middle=3=BS, 2=H1, 1=H2) for a scenario with BS only, with one tier of relays H1, and with two relay hops H1+H2