Mode Selection for Multi-Hop Cellular Networks with Mobile Relays

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***Abstract*— Multi-hop Cellular Networks using Mobile Relays (MCN-MRs) are being investigated to help address certain limitations of traditional single-hop cellular communications. A key element of MCN-MR technologies is the mode selection scheme that selects the most adequate connection mode (traditional single hop cellular or multi-hop link) for each transmission. This paper proposes a novel mode selection scheme that uses context information to select the connection mode, and can adapt its decisions to the operating conditions. This study shows that the proposed scheme outperforms distance-based mode selection schemes, and helps improving the MCN-MR performance with respect to single-hop cellular communications.**

***Index Terms*—Mode selection, multi-hop cellular networks, mobile relay.**

I. Introduction

TRADITIONAL single-hop cellular systems have difficulty in providing homogeneous Quality of Service (QoS) levels across a cell as a result of the effect of distance and surrounding obstacles on the direct link between Base Stations (BSs) and users. This limitation can be partly overcome through the use of relaying techniques in cellular systems; referred to as Multi-hop Cellular Networks (MCNs). Different studies have highlighted the potential benefits of MCN in terms of capacity, energy-efficiency, and traffic offloading [1]. Such benefits are expected from the substitution of long-distance, and generally non-line of sight, single-hop cellular links between a BS and a user with various multi-hop transmissions with improved link budgets. Cellular standards have initially focused on the use of fixed relays (MCN-FR). However, recent experimental studies have also demonstrated the significant benefits that can be obtained with mobile relays (MCN-MR) in different environments [2]. In MCN-MR, the connection between a user and a BS is established through ad-hoc links between the user and mobile relay nodes (RNs), and a final cellular link between an RN and the BS.

The expected MCN-MR benefits can only be achieved in scenarios where a Multi-Hop connection (MH mode) between source and destination guarantees improved link budgets compared to a direct Single Hop cellular link (SH mode). The design of mode selection schemes capable to indentify the optimum connection mode (SH or MH) under different deployment and operating conditions is therefore critical to realize the expected MCN-MR benefits [3]. In this context, this paper proposes and evaluates a novel mode selection scheme that exploits context information available at a BS to decide whether to establish a MH or SH link. In particular, the proposed mode selection scheme uses information about the density of nodes in a cell, and the distance between the BS and the user. Using this information, the proposed scheme evaluates the benefits and risks of establishing a SH or MH connection, and decides the most adequate connection mode considering the deployment and operating conditions.

II. Related Work

Users at the cell edge usually experience lower QoS levels compared to users close to the BS. To enhance their QoS, [4] proposes a mode selection scheme for MCN with fixed relays. The proposed scheme considers the MH mode (using a fixed RN) for users that are a distance to the BS longer than a given threshold. On the other hand, users that are at a distance to the BS shorter than the established threshold transmit using traditional single-hop cellular links (SH). A similar distance-based mode selection scheme is also considered for MCN-MR in [5], where the authors investigate mechanisms to select relay nodes. The distance-based mode selection scheme is compared in [4] against a scheme that selects the connection mode that requires the smaller number of subcarriers in an OFDMA-based MCN-FR setting to achieve a certain performance target given the link quality conditions of the SH or MH links. The obtained results show that MH might not always be the most efficient connection mode, and that mode selection schemes that use context information (in their study, link quality conditions) can outperform distance-based schemes. However, it is important noting that estimating and using the SH and MH link quality conditions has a very significant cost in MCN-MR given the mobility of nodes, and the high number of possible mobile relays. In [6], the authors propose an adaptive mode selection scheme for MCN-MR. The scheme establishes that users always start their transmissions in MH mode given the expected MCN-MR benefits. MH users switch to SH mode if the MH throughput is lower than the throughput that could be obtained in SH mode. This adaptive approach can result in possible throughput benefits. However, handovers between MH and SH modes result in a signalling overhead and transmission delay. Such signalling overhead and delay cost is also present when trying to initiate a transmission in MH mode, and the MH connection is either not possible (e.g. due to the absence of RNs) or inefficient (e.g. due to the presence only of RNs with poor ad-hoc QoS levels). As a result, mode selection schemes should be designed to avoid establishing low

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efficiency or poor performance MH connections. In this context, this paper proposes a novel mode selection scheme designed to minimize inadequate selections of the MH mode in MCN-MR. In particular, the proposed scheme aims to select the connection mode that provides the higher performance considering the possibility to successfully establish each possible connection mode. The proposed scheme bases its mode selection on context information already available at a BS (density of nodes within the cell and distance between the BS and user), thereby reducing the implementation cost. Using this information, the proposed scheme evaluates the benefits and risks of establishing a SH or MH connection. The scheme decides then the most convenient connection mode for the considered deployment and operating conditions.

III. Mode Selection Proposal

The study reported in [7] indicates that most MCN-MR benefits can be obtained considering just 2 hops between source and destination. As a result, this study focuses on the 2 hop scenario illustrated in Fig. 1, where a BS decides for downlink transmissions whether to establish a direct SH link with the destination node (DN) or a MH connection using RN as a relay node.

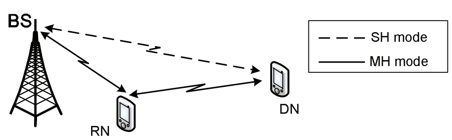

Fig. 1. SH and MH modes in a 2 hop MCN-MR scenario.

A. Mode selection criterion

The proposed mode selection scheme has been designed to assign the connection mode (SH or MH) that provides the higher expected performance. The expected performance is evaluated considering the potential risks and benefits of each connection mode. This is done so that the mode selection scheme does not only consider the potential performance levels that can be obtained by a given connection mode, but also the possible risks that could prevent operating under the conditions necessary to achieve such performance levels. The proposed scheme is then referred to as BRISK (mode selection scheme based on Benefits and RISKs).

The benefit that can be obtained from each possible connection mode is represented by the performance (e.g. throughput) that such mode could achieve if the connection is established under the adequate conditions (e.g. if an adequate RN improving the DN performance is found in the case of MH connections). The benefit is here denoted by $Benefit_m$, with m representing the connection mode (SH or MH). The risk taken when selecting a given connection mode comes from the probability that the transmission cannot be conducted under the conditions required to achieve the expected benefit (e.g. if an adequate RN improving the DN performance cannot be found in the case of MH connections). The risks resulting from trying to establish an m connection is denoted by $Risk_m$. The performance P_m^i that a node DN i could expect from the use of mode m can be expressed as:

$$P_m^i = Benefit_m^i \cdot (1 - Risk_m^i) \quad (1)$$

For each transmission between BS and a DN i, the BRISK proposal selects the connection mode m_i^* that provides a better compromise between benefits and risks, and therefore the higher expected performance:

$$m_i^* = \arg \max_{m \in \{\text{SH,MH}\}} P_m^i \quad (2)$$

The performance of the BRISK scheme depends on an accurate estimation of the expected performance for each connection mode. To improve such accuracy, BRISK exploits context information available at the BS. In particular, the benefits and risks experienced with each connection mode are estimated using information about the density of users in the cell, and the distance between BS and DN i. The BS, which is in charge of the execution of the mode selection scheme, knows the number of users under its coverage, and then the density of nodes in the cell. In addition, the BS can estimate the distance to each node in the cell (not the node position) based, for example, on the signal strength of control messages received at the BS from each node. As a result, BRISK does not require additional overhead to obtain the context information.

B. Benefits and risks of SH and MH connections

This study considers a cellular system (e.g. HSDPA or LTE) with QoS rings (Fig. 2) characterized by varying cellular link quality levels and optimal transmission modes (modulation and coding scheme). A QoS ring R can be defined as the BS area where a given transmission mode is optimum, and is therefore used for cellular communications with nodes located in such ring. R_i represents the QoS ring where node i is located. Rings closer to the BS are generally characterized by better link quality levels, and therefore the use of transmission modes with higher data rates. $R' \succ R$ indicates that a node located at R' has higher data rates than a node located at R.

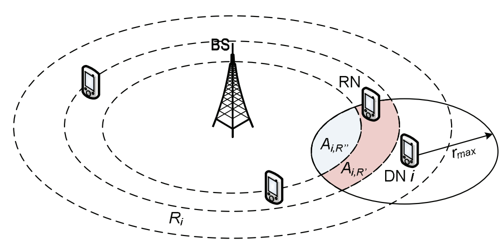

Fig. 2. System scenario and conditions for an MH connection.

Considering the cellular system presented in Fig. 2, it is reasonable to assume that all users within the same QoS ring R experience on average the same benefit when assigned an equal number of radio resources s, which is represented as $Benefit(s,R)$. In this context, the benefit of using a SH link for a communication between BS and DN i depends on the QoS ring R_i where DN i is located and the number of assigned cellular radio resources. The ring R_i where DN i is located is determined by the distance d_i between DN i and its serving BS. As a result, the SH benefit can be expressed as a function of d_i and the number of cellular radio resources s_i assigned to DN i:

$$Benefit_{SH}^{i}(s_i, d_i) \equiv Benefit(s_i, R_i) \quad (3)$$

The BS can establish a direct SH link with a user located in its coverage area as long as radio resources are available. In this context, the risk of establishing a SH connection is related to the availability of radio resources in the cell. Given that cellular radio resources are also used to establish the BS-RN link in a MH connection, the availability of cellular radio resources will then influence equally both SH and MH connection modes. Considering that the risk that cellular radio resources are unavailable is present for all connection modes, it can be omitted in the estimation of the risk factor for each mode. As a result, the risk resulting from selecting the SH mode for a transmission between BS and DN i is then:

$$Risk_{SH}^{i}(d_i) = 0 \quad \forall d_i \le d_{cell} \quad (4)$$

where d_{cell} represents the cell radius.

The expected SH performance for a DN i at a distance d_i from the BS can then be expressed as follows:

$$P_{SH}^{i}(s_i, d_i) = Benefit_{SH}^{i}(s_i, d_i) \equiv P(s_i, R_i) = Benefit(s_i, R_i) \quad (5)$$

where $P(s_i, R_i)$ represents the average performance experienced by nodes located in the QoS ring R_i when assigned s_i cellular radio resources.

MH can improve the performance at DN i over SH if the BS can find a RN located in a ring R with higher data rates than R_i ($R \succ R_i$). In addition, it is necessary that the distance between DN i and RN is shorter than a maximum distance r_{max} that allows transferring the RN performance to the DN i [8]. MH can then provide DN i with a higher performance than SH if BS can find a RN within an area A_i defined as the union of the intersection areas $A_{i,R}$ between a circle $C(i, r_{max})$ centred in DN i with radius r_{max} and the rings R that satisfy $R \succ R_i$:

$$A_i = \bigcup_{R|R \succ R_i} A_{i,R} \quad (6)$$

$$A_{i,R} = R \cap C(i, r_{\max}) \quad (7)$$

The MH benefit for DN i can then be expressed as:

$$Benefit_{MH}^{i}(s_i, d_i) = \frac{\sum_{R|R \succ R_i} P(s_i, R) \cdot \mathrm{prob}^{\mathrm{RN}}(A_{i,R})}{\sum_{R|R \succ R_i} \mathrm{prob}^{\mathrm{RN}}(A_{i,R})} \quad (8)$$

where $\mathrm{prob}^{\mathrm{RN}}(A_{i,R})$ represents the probability to find at least one RN within the area $A_{i,R}$, and $P(s_i, R)$ represents the performance of the cellular link between BS and a RN located in R when s_i cellular radio resources are assigned to such link. It is important highlighting that d_i influences the intersection area $A_{i,R}$, and consequently $\mathrm{prob}^{\mathrm{RN}}(A_{i,R})$. As it will be shown in Section IV, this probability is also dependent on the density of users in the cell.

Trying to establish a MH connection has non negligible risks. First, there is the risk that the BS cannot find a RN with higher cellular performance than a potential SH link to DN. Second, even if such RN can be found, it is possible that the RN-DN ad-hoc link does not have sufficient quality to transfer the RN performance to the DN. If any of these two cases occur, the MH connection will result in a lower performance compared to a direct SH link between DN and BS. In this context, the risks $Risk_{MH}^{i}$ resulting from trying to establish a MH connection for DN i derive from the probability of not being able to find a RN within A_i:

$$Risk_{MH}^{i}(d_i) = 1 - \mathrm{prob}^{\mathrm{RN}}(A_i) \quad (9)$$

where $\mathrm{prob}^{\mathrm{RN}}(A_i)$ represents the probability to find at least one RN within the area A_i (this probability is also dependent on the density of users in the cell). $Risk_{MH}^{i}$ is defined as a function of d_i since this distance influences the intersection area A_i, and consequently $\mathrm{prob}^{\mathrm{RN}}(A_i)$. The expected performance of a MH connection $P_{MH}^{i}(s_i, d_i)$ can then be computed using expressions (1), (8) and (9).

A complete definition of the SH and MH performance requires defining the *Benefit*(s,R) function. The benefit that a user will obtain when assigned a connection mode needs to reflect the user satisfaction level. This is a challenging task since user satisfaction is a subjective concept that heavily depends on user perceptions. The evaluation of the proposed mode selection scheme is conducted in this paper (Section IV) considering scenarios with web users. For these users, the *Benefit*(s,R) is here represented as a function of the cellular throughput th (in Mbps) experienced at the RN (MH mode) or DN (SH mode). This throughput depends on the RN or DN location (and therefore R) and the number of assigned cellular radio resources s. The following benefit function has been defined considering the web model presented in [9] and the user satisfaction indications provided in 3GPP TS 22.105:

$$Benefit(s,R) = \begin{cases} 0 & \text{if } th \le 1 \\ \mathrm{A} \cdot \exp(\mathrm{B} \cdot (th - 1) + 0.24 & \text{if } 1 < th \le 2.3 \\ 1 - \mathrm{C} \cdot \exp(-\mathrm{D} \cdot th) & \text{if } 2.3 < th \end{cases} \quad (10)$$

with $\mathrm{A} = 0.00013, \mathrm{B} = 0.0056, \mathrm{C} = 2.13$ and $\mathrm{D} = 0.0025$

The reader is referred to [10] for additional information on the definition of this function. Other benefit functions could certainly be defined based on different satisfaction criterion. In any case, the impact of the benefit function on the outcome of the study is limited since this study is aimed at comparing the performance of BRISK with other schemes and connection modes, and not at establishing absolute performance values.

C. Interaction between the mode selection and radio resource management schemes

The SH and MH performance is a function of the number of assigned cellular radio resources s_i[1]. The SH and MH performance depends then on the RRM (Radio Resource Management) policy implemented to distribute radio resources, and it is necessary to define how the mode selection and RRM schemes interact. First of all, the mode selection scheme identifies the optimum connection mode for all possible radio resource assignments. In particular, and

[1] s_i is used for the direct link between BS and DN i in the case of SH, and for the cellular link between BS and RN in the case of MH.

following (2), the scheme determines $m_i^*(s)$ for all possible values of $s \in [1,S]$, with S representing the maximum number of available cellular radio resources in the cell. The expected performance for each possible radio resource assignment s can then be expressed as:

$$P(s,d_i) = \max\left\{P_{SH}^i(s,d_i), P_{MH}^i(s,d_i)\right\} \quad (11)$$

Considering all possible radio resource assignments, it is possible to compute the expected performance P^i of DN i:

$$P^i = \sum_{s=1}^{S} P(s,d_i)\cdot y_i^s \quad (12)$$

with y_i^s representing a binary variable equal to one if user i is assigned s radio resources, and equal to zero if not.

The RRM policy is then in charge of deciding the value of y_i^s for each transmission, and therefore the number of assigned cellular radio resources. This study implements an adapted version of the MAXIHU (MAXImum Homogeneous Utility values) RRM scheme that was initially proposed by the authors in [10] for heterogeneous networks. In particular, MAXIHU is applied to decide for each possible mode (SH or MH), the number of radio resources to be used by their cellular links. MAXIHU is aimed at providing the highest possible homogeneous performance to all users. To this aim, MAXIHU seeks to maximize the multiplication of the performance perceived by all active users in the system, which results in the following objective function:

$$\max \prod_{i=1}^{n} P^i = \max \sum_{i=1}^{n} \ln P^i \quad (13)$$

where n corresponds to the total number of active users in the cell. To obtain the optimal solution to the modeled problem, MAXIHU makes use of integer linear programming techniques[2]. Following (12), the objective function can be expressed linearly as[3]:

$$\max \sum_{i=1}^{n}\sum_{s=1}^{S} \ln\left(P(s,d_i)\right)\cdot y_i^s \quad (14)$$

The optimum solution of the objective function depends on various restrictions that also need to be expressed linearly. First, the solution is conditioned by the limited number of available cellular radio resources, which can be expressed as:

$$\sum_{i=1}^{n}\sum_{s=1}^{S} s\cdot y_i^s \le S \quad (15)$$

The second restriction concerns the fact that only one y_i^s variable can be equal to one for each user:

$$\sum_{s=1}^{S} y_i^s \le 1 \qquad \forall i \quad (16)$$

IV. Performance Analysis

A. Evaluation Environment

The performance of the proposed mode selection scheme is evaluated using a C++ software simulating a single cell with a 1000m radius. DN users request web browsing sessions following the model reported in [9][4]. Users are initially distributed across the cell following an homogeneous Poisson distribution with average density ρ. Different node densities have been evaluated for typical suburban and low density urban scenarios (see Table I) in order to analyze the capability of the proposed mode selection scheme to select the optimum connection mode (SH or MH) under different operating conditions. RN and DN nodes move following the *Random Direction* model with [V_{min}, V_{max}]=[0, 3m/s] and [D_{min}, D_{max}]=[0, 2π]. The selected mobility model results in a uniform distribution of nodes within the cell. As a result, the probability to find at least a RN within an area A ($\text{prob}^{RN}(A)$) is computed following a Poisson distribution as follows:

$$\text{prob}^{RN}(A) = 1-\exp(-\rho A) \quad (17)$$

This study considers that the ad-hoc connection between RN and DN is established using IEEE 802.11g. BRISK can be applied to any cellular technology. In this study, HSDPA (High Speed Downlink Packet Access) has been selected for the SH transmissions, and the cellular link between BS and RN in the case of MH connections. These two technologies were chosen due to the availability of an empirical 2-hops MH throughput model in [8] that is here used to model the MH throughput. Based on the model reported in [8], r_{max} has been set equal to 150m. This study considers the HSDPA transmission modes associated to the 30 CQI values defined for category 10 terminals (3GPP TS 25.214). Cellular HSDPA data rates are selected based on the distance of users to the BS, and therefore the ring where users are located (the rings are related to the CQI values).

If a MH connection is to be established and there are several candidate RNs within A_i, the RN closer to the BS is selected. If no RNs are present within A_i, the selected RN is the one that is closer to DN and at a shorter distance to the BS than DN.

TABLE I
EVALUATION SCENARIOS AND NODE DENSITIES

Scenario	Number of nodes in cell	Node density ρ (nodes/km^2)	Nodes within a 150m radius circumference
100RN	100	31.8	2.25
400RN	400	127.3	9
1000RN	1000	318.3	22

B. Performance Results

The performance of the proposed mode selection scheme is compared against other schemes[5]. In particular, the performance is compared against that obtained when operating traditional SH cellular communications (SH), and against that obtained with the distance-based mode selection scheme (DMS) proposed in [4] and [5]. In an actual implementation, DNs that are not able to establish an adequate MH connection will always have the possibility to switch to the direct SH link

[2] The integer lineal programming optimization problems are solved using the linear optimization software CPLEX.

[3] More information on how to obtain (14) can be found in [10].

[4] The average time between sessions has been set equal to 10s. It is important noting that similar trends as those reported in this paper have been observed for other traffic services and scenarios with various traffic services. These results are here omitted due to length restrictions.

[5] For a fair comparison, all the reference schemes also use MAXIHU as their RRM scheme.

(this change entails additional transmissions delays and overhead). However, changes between connection modes are not allowed in this study for all schemes in order to focus on the impact of the mode selection process.

DMS has been implemented following the details provided in [5] for MCN-MR. This scheme always selects the MH mode for users that are at a distance longer than d_{ref} from the BS ($d_i > d_{ref}$), and the SH mode for users with $d_i \leq d_{ref}$. DMS selects RNs for MH connections that are located at a distance shorter than d_{ref} from the BS. In addition, the distance between RN and DN must be shorter than the communications range for the ad-hoc link. Following the measurements reported in [8], this range has been set equal to 210m since the measured throughput at the DN was equal to zero for longer distances between RN and DN. The measurements reported in [8] show that if the distance between DN and RN is shorter than a maximum distance r_{max} equal to 150m, the performance at the DN is equal to that measured at the RN. MCN technologies are expected to mainly benefit users at long distances to the BS, and in particular those at the border cell. As a result, d_{ref} has been set to 850m considering that the cell radius and r_{max} are equal to 1000m and 150m respectively.

Fig. 3 compares the average throughput per assigned radio resource as a function of the distance of DN to the BS[6]. This metric is used in this study to analyze the operation and performance of mode selection schemes independently of the radio resource allocation. Fig. 4 represents the gain that can be obtained in terms of throughput per assigned radio resource by the mode selection schemes with respect to SH. The obtained results show that BRISK always provides a performance equal or higher than traditional SH communications. The improvements obtained by BRISK with respect to SH increase with the density of nodes and the distance between DN and BS. In particular, Fig. 3 and Fig. 4 show that the throughput gains obtained with BRISK are particularly relevant for users at long distances to the BS and at the cell edge. This trend is also illustrated in Fig. 5 that represents the average ratio between the benefits of selecting the MH mode ($Benefit_{MH}$) and the benefits of selecting the SH mode ($Benefit_{SH}$) as a function of the distance between DN and BS[7]. Fig. 5 shows that the MH benefit significantly increases with respect to the SH benefit for distances longer than 500m; the increase augments with the density of nodes[8]. On the other hand, users

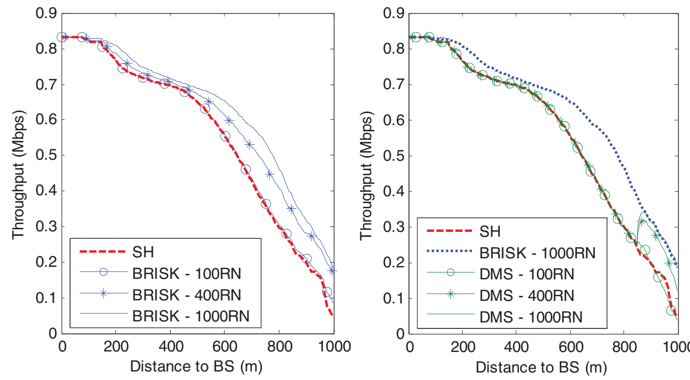

Fig. 3. Throughput comparison (for different scenarios) as a function of the distance between DN and BS.

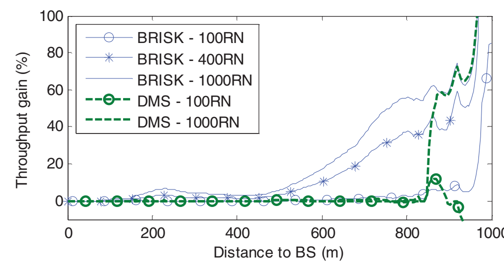

Fig. 4. Throughput gain obtained with the mode selection schemes with respect to SH.

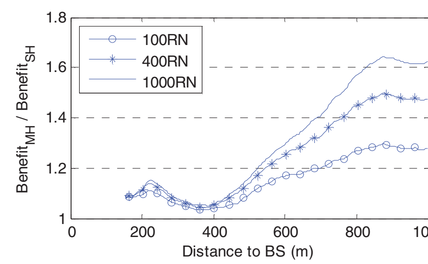

Fig. 5. Ratio of benefits as a function of the distance between DN and BS when applying BRISK.

close to the BS already achieve good throughput levels with traditional SH communications, and the MH mode does not provide significant added benefits for these users. As a result, users close to the BS (distances lower than 500m approximately) do not use the MH mode with BRISK (Fig. 6) unless there is a low risk in doing so (Fig. 7). Fig. 6 represents, as a function of the distance between DN and BS, the percentage of transmissions for which BRISK selects the MH mode. Fig. 7 shows the risk of selecting the MH mode when applying BRISK. The results shown in Fig. 6 and Fig. 7 show that when the density of nodes is high (e.g. 1000RN scenario), a high percentage of transmissions are done with the MH mode when applying BRISK (Fig. 6). This is also the case for users close to the BS since the risk of selecting the MH mode is very low with high node densities (Fig. 7). On the other hand, when the density decreases, the risk increases for users close to the BS. As a result, BRISK reduces the selection of the MH mode for these users. It is important emphasizing that the obtained results demonstrate the capacity of BRISK to adapt its mode decisions to the operating conditions (density

[6] The performance of the mode selection schemes depends on the density of nodes, and therefore the probability of finding a RN. The SH performance does not depend on such probability.

[7] DNs located at distances to the BS shorter than 150m do not select the MH mode since the RNs cannot improve the performance compared to SH. This explains why the results shown in Fig. 5, Fig. 6 and Fig. 7 are only represented for distances longer than 150m.

[8] Fig. 5 shows a reduction in the benefit of MH with respect to SH for DNs located at distances to the BS between 250m and 400m. This effect is not due to the design of BRISK, but instead to the HSDPA CQIs. In particular, the effect is due to the fact that DNs located in this area experience a lower throughput increase when establishing a MH connection compared to DNs located at shorter distances to the BS. For example, a DN located 200m away from the BS could reach a throughput per assigned radio resource of 852kbps if it establishes a MH connection with a RN located 100m away from the BS. This represents an increase of 6% with respect to the SH throughput (807.04kbps). The throughput improvement that can be achieved with an MH connection for a DN node located, for example, 375m away from the BS is only 0.7% (725kbps compared to 720kbps).

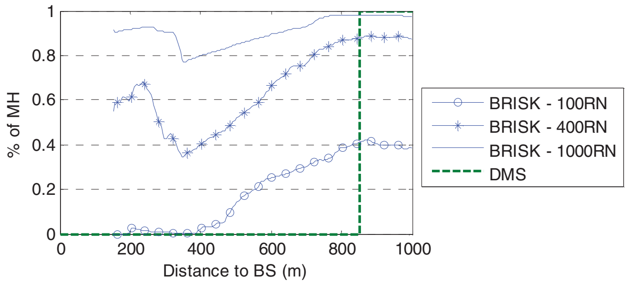

Fig. 6. Percentage of transmissions for which BRISK selects MH as a function of the distance between DN and BS.

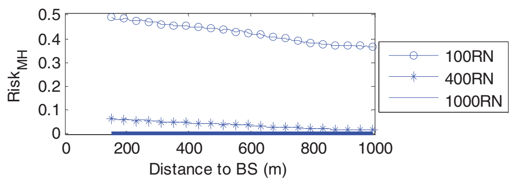

Fig. 7. Risk of selecting MH as a function of the distance between DN and BS when applying BRISK.

of nodes and distance to the BS).

Fig. 3 and Fig. 4 also show that BRISK improves the throughput with respect to the distance-based mode selection scheme. The improvement is observed for all densities and all possible locations of DN. DMS is only capable to match the throughput of BRISK in the case of the higher densities. In these scenarios, only DNs located at distances to the BS longer than 850m can achieve throughput levels close to that obtained with BRISK. This is due to the fact that DMS does not exploit MH communications for users at distances to the BS shorter than d_{ref} even if the density of nodes is such that adequate MH connections could be established. In the case of low densities, DMS achieves a throughput even lower than that obtained with traditional SH cellular communications. Table II compares the operation of BRISK and DMS. The depicted results show that DMS increases the number of incorrect mode selections for all scenarios (the number decreases with the density of nodes). This number is represented in Table II with the percentage of transmissions that selected a MH mode, and such mode was not capable to increase the throughput with respect to traditional SH cellular communications. The results reported in this paper did not consider the possibility to switch active transmissions between MH and SH modes. This was prevented to focus on the mode selection process. In addition, it is important noting that switching active transmissions between MH and SH modes has a cost in terms of signalling overhead and transmission delays. For comparison purposes, Table II also depicts the percentage of transmissions that would request a handover from MH to SH if permitted. The reported results show that BRISK reduces this percentage for all scenarios, highlighting once more that BRISK improves the selection of the most adequate connection mode.

Finally, it is important to highlight the low computational complexity of the proposed mode selection scheme, which is of order O(n), where n is the number of active transmissions in the cell. On the other hand, the implementation feasibility of the MAXIHU RRM technique was demonstrated in [10].

TABLE II
COMPARISON OF BRISK AND DMS

	Percentage of MH transmissions that do not improve the SH throughput		Percentage of transmissions that could request a handover from MH to SH	
	BRISK	DMS	BRISK	DMS
100RN	30.06	39.28	8.08	12.46
400RN	1.95	10.29	1.41	3.15
1000RN	0.92	3.67	0.84	1.13

V. CONCLUSIONS

This paper has proposed and evaluated a MCN-MR mode selection scheme with low implementation cost. The proposed scheme selects the most adequate connection mode considering information about the density of nodes and the distance between BS and DN. This information is used to estimate the benefits and risks present in establishing a SH or a MH connection. The performance of the proposed scheme has been compared against that obtained with a distance-based mode selection scheme and with traditional single-hop cellular communications. The obtained results show that the proposed mode selection scheme improves the percentage of correct mode selections, and consequently the throughput performance.

ACKNOWLEDGMENTS

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