A Distributed Algorithm for Energy Saving in Nomadic Relaying Networks

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***Abstract*—This paper presents a distributed cell selection algorithm for energy savings in nomadic networks where randomly distributed devices (e.g., parked vehicles) serve as potential relay nodes. Based on load information and link quality, the nomadic relays and subsequently the users select access points so as to minimize the energy consumption in the network. Furthermore, admission control mechanisms are incorporated at the base stations and nomadic relay nodes to avoid overloading. We prove the convergence of our algorithm, while simulations show that the proposed algorithm has a great potential for reducing the energy consumption compared with traditional cell selection algorithms.**

I. Introduction and System Model

As the modern information technology evolves into a new era, revolutionary social and industrial standards are speculated, where requirements on efficiency and sustainability are treated with a very high priority. Meanwhile, the boosting data traffic volume with dynamic temporal-spatial patterns is envisaged in the upcoming years, bringing about tremendous challenges on the flexibility and accuracy in the design of the 5G cellular systems [1].

Nomadic networks, defined as networks with randomly distributed nodes (e.g., parked vehicles with on-board relay infrastructures) acting as potential relay node (RN)s, are regarded as an important 5G system component to cope with the increasing dynamic demand for wireless access [2]. While the location of operator-deployed RNs can be optimized by means of network planning tools, the location of the vehicle mounted RNs in a nomadic network, referred to in this paper also as *nomadic RNs* or *nomadic nodes*, is out of control of a network operator, and therefore is considered to be random. Moreover, their availability and position may change in time (hence, the term "nomadic") due to battery state and node movement. The nomadic RNs operate in a self-organized fashion and are in general activated and deactivated based on capacity, coverage, load balancing or energy efficiency demands. Therefore, the concept of a nomadic network describes an effective extension of the cellular infrastructure that allows for a dynamic network deployment.

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In our previous works [3] [4], we have identified the following key problems in a nomadic network:

- Relay Selection (RS): selection and subsequent assignment of RNs to base station (BS)s;
- User Association (UA): assignment of user equipment (UE)s to RNs (two-hop relaying) or BSs (direct communications);
- Radio Resource Management (RRM): a flexible allocation of radio resources of BSs and RNs for improving spectral and energy efficiency.

Furthermore, the energy saving problem has raised enormous attentions in the telecommunication industry, recently. Research works extensively studied the energy saving problem on both theoretical fundamentals [5], [6] and practical solutions [7], [8], [9]. Driven towards the sustainability of the future, we investigated the energy saving problem [3] in nomadic networks, where we formulated an optimization framework as an RS-UA problem and provided theoretical analyses and centralized algorithms for the optimization problem.

In this paper, we adapt the energy saving optimization framework in our previous work [3]. In order to enable a more efficient and practical implementation, we propose here a distributed algorithm for cell selection and admission control, where a node (UE or RN) selects a cell (BS or RN) in an attempt to connect to an access point, while the cell determines if the connection request can be granted based on load situations. We show that the algorithm ensures that the constraints of the optimization problem are satisfied during iterations. Furthermore, we prove that the approximation of the optimization objective decreases in each iterations. Simulations confirm that the algorithm converges fast in various network configurations and significantly reduces the network energy consumption in low load situations.

The rest of the paper is organized as follows: Section II introduces the system model and presents the energy saving problem. In Section III, the distributed cell selection and admission control algorithm is proposed along with the proof of convergence. Numerical evaluations are given in the following section, while the final section completes the paper with conclusive remarks.

II. System Model and Problem Formulation

Following the same model as in our previous work [3], we consider the downlink channel of a nomadic relaying network with M BSs, N UEs and K RNs. The set of BSs, UEs and RNs are denoted by, respectively, $\mathcal{B}$, $\mathcal{U}$ and $\mathcal{R}$. We use direct links, access links and relay links to refer to the BS-UE, RN-UE and BS-RN links, respectively.[2] The amount of bandwidths (in Hz) at BSs and RNs are fixed and grouped in a vector $\mathbf{b} = (b_1, \dots, b_M, b_{M+1}, \dots, b_{M+K})^T$. The required minimum rates (in bit/s) of the UEs is denoted by $\mathbf{r} = (r_1, \dots, r_N)^T$. Note that each UE can be connected either to an RN or directly to a BS, while an RN can only be connected to a BS. The Spectral Efficiency (SE) of a link (i,j) is assumed to be (in bit/s/Hz)

$$\omega_{i,j} = \log(1 + \tau_{i,j}), \tag{1}$$

where $\tau_{i,j}$ denotes the corresponding Signal to Interference plus Noise Ratio (SINR). Throughout the paper we assume the following:

(A.1) The parameters $\mathbf{r}$ and $\mathbf{b}$ are known or can be estimated reliably at a central network control unit .

(A.2) While access links and direct links interfere with each other, the RNs use separate time-frequency resources on the relay links and access links. Hence the access links do not interfere with the relay links.

(A.3) We consider in this work a static worst-case interference model as in many other works [10] [11] [12].

As a result, the SINR of a link (i,j) is given by

$$\tau_{i,j} = \begin{cases} \frac{P_{i,j}}{\sum_{d\in\mathcal{B}, d\neq i} P_{d,j} + \sigma_j} & \text{for } j \in \mathcal{R}, \\ \frac{P_{i,j}}{\sum_{d\in\mathcal{B}\bigcup\mathcal{R}, d\neq i} P_{d,j} + \sigma_j} & \text{for } j \in \mathcal{U}, \end{cases} \tag{2}$$

Herein, σ_j is the receiver-side noise power and $P_{i,j}$ is the received signal or interference power at UE or RN j, either from a BS or from an RN. Note that $\tau_{i,j} > 0$ always holds, since both received power and interference plus noise are positive values. Furthermore, a positive $\tau_{i,j}$ exists also for the case when both $i, j \in \mathcal{R}$, however, we do not allow multi-hop communication and hence there is no connection between RNs in this work.

A. Assignment and Load Function

Let $x_{i,j}$ denote the assignment variable: $x_{i,j} = 1$ if there is an active link between cell i and node j, and $x_{i,j} = 0$ otherwise. Then, we introduce the assignment matrix to be defined as

$$\mathbf{X} \triangleq \begin{pmatrix} \mathbf{X}^{(\text{m,n})} & \mathbf{X}^{(\text{m,k})} \\ \mathbf{X}^{(\text{k,n})} & \mathbf{X}^{(\text{k,k})} \end{pmatrix} \in \{0,1\}^{(M+K)\times(N+K)}, \tag{3}$$

where $\mathbf{X}^{(\text{m,n})} \in \{0,1\}^{M\times N}$, $\mathbf{X}^{(\text{k,n})} \in \{0,1\}^{K\times N}$ and $\mathbf{X}^{(\text{m,k})} \in \{0,1\}^{M\times K}$ are assignment matrices for the direct, access and relay links, respectively. Note that $\mathbf{X}^{(\text{k,k})}$ captures the connections between RNs and is set to be an all zero matrix since multi-hop communication is not allowed. Further, we define $\boldsymbol{\rho} \triangleq [\rho_1, \dots \rho_M, \rho_{M+1}, \dots, \rho_{M+K}]^T \in \mathbb{R}_+^{M+K}$, $i \in \mathcal{B}\bigcup\mathcal{R}$ to be the vector of loads at the BSs and RNs, where the i-th entry of the load vector can be calculated as

$$\begin{aligned} \rho_i &= \rho_i^{(1)} + \rho_i^{(2)}, \quad i \in \mathcal{B}\bigcup\mathcal{R} \\ &= \underbrace{\sum_{j\in\mathcal{U}} \frac{r_j^{(\text{n})}}{b_i\omega_{i,j}} x_{i,j}}_{\text{direct/access links}} + \underbrace{\sum_{k\in\mathcal{R}} \frac{r_k^{(\text{k})}}{b_i\omega_{i,k}} x_{i,k}}_{\text{relay links}} \\ &= \sum_{j\in\mathcal{U}} \frac{r_j^{(\text{n})}}{b_i\omega_{i,j}} x_{i,j} + \sum_{k\in\mathcal{R}} \sum_{j\in\mathcal{U}} \frac{r_j^{(\text{n})}}{b_i\omega_{i,k}} x_{k,j} x_{i,k}. \end{aligned} \tag{4}$$

Herein, $\rho_i^{(1)}$ and $\rho_i^{(2)}$ refer to the load corresponding to the UEs (direct/access links) and RNs (relay links), respectively, while $r_j^{(\text{k})}$ is the rate requirement of an RN, which is the sum rate of all the UEs connected to this RN:

$$r_k^{(\text{k})} = \sum_{j\in\mathcal{U}} r_j^{(\text{n})} x_{k,j}, \quad \text{for } j \in \mathcal{U}, k \in \mathcal{R}\,. \tag{5}$$

Note that the load vector depends on the assignments, and therefore we have $\boldsymbol{\rho} = \boldsymbol{\rho}(\mathbf{X})$. Furthermore, $\boldsymbol{\rho}(\mathbf{X})$ expresses bandwidth utilization ratio and is smaller than one.

B. Optimization Problem for Energy Saving

To this end, we can formulate an energy consumption minimization problem as follows[3]:

$$\begin{aligned} \min_{\mathbf{X}} \quad & \text{F}(\mathbf{X}) := \sum\nolimits_{i=1}^{M+K} c_i ||\mathbf{e}_i^T \mathbf{X}\mathbf{1}||_0 && \text{(6a)} \\ \text{subject to} \quad & \boldsymbol{\rho} \leq \mathbf{1} && \text{(6b)} \\ & \mathbf{X}^T \cdot \mathbf{1} = \mathbf{1} && \text{(6c)} \\ & \mathbf{X} \in \{0,1\}^{(M+K)\times(N+K)}. && \text{(6d)} \end{aligned}$$

Herein, $\mathbf{c} = (c_1, \dots, c_M, c_{M+1}, \dots, c_{M+K})^T \in \mathbf{R}_+^{(M+K)}$ is the vector of energy consumptions of BSs and RNs. While $\mathbf{e}_i^T\mathbf{X}$ in (6a) yields the i-th row of $\mathbf{X}$, $||\cdot||_0$ denotes the l_0-norm, which is the cardinality of the set of non-zero elements in a vector. Following [10], we assume that the fixed energy consumption (hardware, signal processing, etc) dominates the dynamic energy consumption (power radiation, etc), i.e., if node i, BS or RN, is active (at least one attached node), it consumes a constant amount of energy c_i. Therefore, the objective (6a) reflects the total energy consumption. The element-wise inequality "$\leq$" in (6b) takes into account limitations on the available resources. Moreover, (6c) and (6d) together state that UEs and RNs must be connected to the network.

[2] Throughout this paper, notations with superscripts (m), (n) and (k) are variables associated with BSs, UEs and RNs, respectively, while (m,n), (k,n) and (m,k) are referring to the direct, access and relay links, respectively.

[3] Throughout the paper, $\mathbf{1}^l(\mathbf{0}^l)$ refers to column vector of length l. If not specified, $\mathbf{1}(\mathbf{0})$ is a column vector with proper length for matrix operator. Furthermore, $\mathbf{1}^{m\times n}(\mathbf{0}^{m\times n})$ refers to an $m \times n$ matrix of ones(zeros).

III. Distributed Energy Saving Algorithm

The problem in (6) is intractable due to the non-continuous nature of the objective function which requires relaxations. Furthermore, the load constraint is proven to be non-convex [3], resulting in a higher level of complexity in solving the optimization problem. We provided in the previous work centralized optimization algorithms which significantly reduce the total energy consumption, thereby raising issues of computation complexity in large networks. In the following, we introduce a novel cell selection criterion and propose a distributed energy saving algorithm for cell selection and admission control.

A. Approximation of Objective

In order to make the problem tractable, we first adopt the same approach as in [10] to approximate the objective function by using a *strictly concave function* that takes the load $\boldsymbol{\rho}$ as argument:

$$\begin{aligned} \mathrm{F}(\mathbf{X}) &= \sum\nolimits_{i=1}^{M+K} c_i ||\rho_i||_0 \\ &\approx \sum_{i=1}^{M+K} \frac{c_i(\log(\epsilon+\rho_i)-\log(\epsilon))}{\log(1+\epsilon^{-1})} = \mathrm{U}_\epsilon(\boldsymbol{\rho}), \end{aligned} \tag{7}$$

where $\epsilon > 0$ is a sufficiently small positive constant and $\lim_{\epsilon\to 0}\mathrm{U}_\epsilon(\boldsymbol{\rho}) = \mathrm{F}(\mathbf{X})$ for every $\mathbf{X}$ that induces the load $\boldsymbol{\rho}$. Note that $\mathbf{e}_i^T\mathbf{X}\mathbf{1}$ is the number of the connected nodes to cell i, therefore the load $\rho_i = 0$ if and only if $\mathbf{e}_i^T\mathbf{X}\mathbf{1} = 0$, i.e., no node is connected. Hence, $||\mathbf{e}_i^T\mathbf{X}\mathbf{1}||_0 = ||\rho_i||_0$, therefore the first equality holds, and $\mathbf{X}$ is said to induce $\boldsymbol{\rho}$.

B. Distributed Cell Selection and Admission Control

1) Cell Selection: The constraints in (6c) and (6d) can be fulfilled by running distributed cell selection algorithms, i.e., each UE or RN chooses one access point based on radio link and network measurement. By doing this, the network assignment is chosen in a decentralized manner such that each node is trying to attach to only one cell. In time slot (t), the cell selection criterion can be explained as follows:

(i) Each BS or RN i broadcasts its current load $\rho_i^{(\mathrm{t})}$.

(ii) RN j selects a BS from the set of non-overloaded BSs (denoted as $\bar{\mathcal{B}}_j$) by solving the following problem:

$$i = \mathrm{argmin}_{i\in\bar{\mathcal{B}}_j} \frac{1}{(\rho_i^{(\mathrm{t})}+\epsilon)\omega_{i,j}b_i} \tag{8}$$

(iii) Each UE j selects a cell i from the set of the accessible BSs and RNs ($\bar{\mathcal{B}}_j$ and $\bar{\mathcal{R}}_j$) according to:

$$i = \mathrm{argmin}_{i\in\bar{\mathcal{B}}_j\bigcup\bar{\mathcal{R}}} f_{i,j} \tag{9}$$

where

$$f_{i,j} = \begin{cases} \frac{1}{(\rho_i^{(\mathrm{t})}+\epsilon)\omega_{i,j}b_i} & i\in\bar{\mathcal{B}}_j \\ \frac{1}{(\rho_i^{(\mathrm{t})}+\epsilon)\omega_{i,j}b_i} + \frac{\sum_{h\in\bar{\mathcal{B}}} x_{hi}}{(\rho_h^{(\mathrm{t})}+\epsilon)\omega_{h,j}b_h} & i\in\bar{\mathcal{R}}_j \end{cases} \tag{10}$$

Note that the set of non-overloaded or accessible cells is identified by taking into account both the broadcasted load

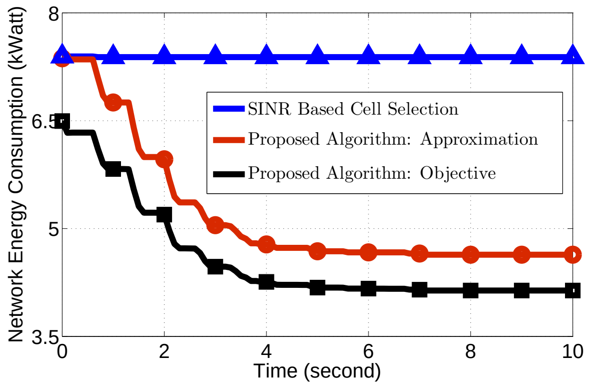

Fig. 1. Convergence of the algorithm.

$\rho_i^{(t)}$ and the predicted resource consumption for link (i,j). If the remaining amount of resources of cell i, which equals $1-\rho_i^{(t)}$, supports serving node j through link (i,j), then cell i belongs to the set of candidates.

2) Admission Control: The cell selection algorithm may violate the constraint in (6b), since the broadcasted load information of a cell may become outdated after other nodes have connected to the cell due to uncoordinated accesses. Therefore, we introduce an admission control mechanism at the BSs and RNs such that the access is only allowed when the constraint $\rho < 1$ holds after attaching the node, otherwise, a rejection will be sent and the RN or UE should keep the previous connections such that $x_{i,j}^{(\mathrm{t}+1)} = x_{i,j}^{(\mathrm{t})}$.

C. Convergence in the Objective

Now that the constraints of the energy saving problem are satisfied, we show in the following how the proposed distributed algorithm converges and how it optimizes the approximation of the objective function. Since $\mathrm{U}_\epsilon(\boldsymbol{\rho}) \geq 0$ holds for all $\boldsymbol{\rho} \geq \mathbf{0}$, it suffices for convergence in objective to show that the sequence $\{\mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t})})\}_{\mathrm{t}=0}^{\infty}$ is non-increasing. In order to prove this, we denote $\boldsymbol{\rho}^{(\mathrm{t}')}$ and $x_{i,j}^{(\mathrm{t}')}$ to be, respectively, the load state vector and assignment of link (i,j) after step (ii) and before step (iii) in time slot (t) and we show in the following that $\mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t}+1)}) \leq \mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t}')}) \leq \mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t})})$. By the strict concavity of $\mathrm{U}_\epsilon(\boldsymbol{\rho})$ given by (7), we have:

$$\begin{aligned} & \mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t}')}) - \mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t})}) \\ \leq\ & \nabla\mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t})})^T(\boldsymbol{\rho}^{(\mathrm{t}')}-\boldsymbol{\rho}^{(\mathrm{t})}) \\ =\ & \sum_{i\in\mathcal{B}} \frac{1}{(\rho_i^{(\mathrm{t})}+\epsilon)\log(1+\epsilon^{-1})} \sum_{j\in\mathcal{R}} \frac{r_j^{(\mathrm{k})}(x_{i,j}^{(\mathrm{t}')}-x_{i,j}^{(\mathrm{t})})}{b_i\omega_{i,j}} \\ =\ & \sum_{j\in\mathcal{R}}\sum_{i\in\mathcal{B}} \frac{r_j^{(\mathrm{k})}(x_{i,j}^{(\mathrm{t}')}-x_{i,j}^{(\mathrm{t})})}{b_i\omega_{i,j}(\rho_i^{(\mathrm{t})}+\epsilon)\log(1+\epsilon^{-1})} \\ =\ & \sum_{j\in\tilde{\mathcal{R}}}\sum_{i\in\bar{\mathcal{B}}_j} \frac{r_j^{(\mathrm{k})}(x_{i,j}^{(\mathrm{t}')}-x_{i,j}^{(\mathrm{t})})}{b_i\omega_{i,j}(\rho_i^{(\mathrm{t})}+\epsilon)\log(1+\epsilon^{-1})}, \end{aligned}$$

where $\tilde{\mathcal{R}}$ is the set of admitted RNs. The last equality holds since the admission control rule ensures that $x_{i,j}^{(\mathrm{t}')} - x_{i,j}^{(\mathrm{t})} = 0$

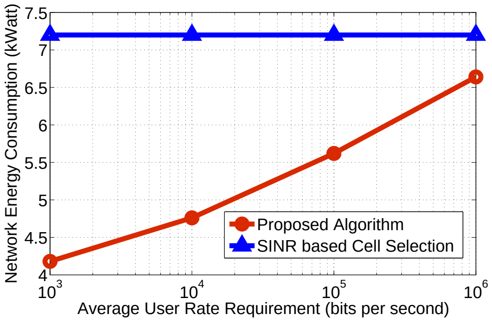

Fig. 2. Network energy consumption against user rate requirements.

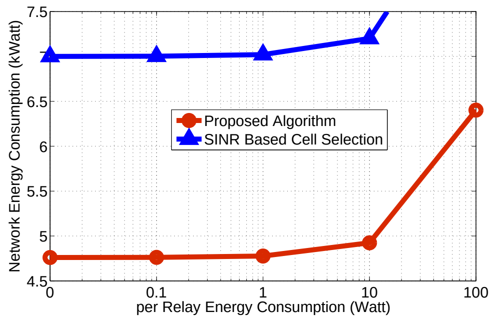

Fig. 4. Network energy consumption against per relay energy consumption.

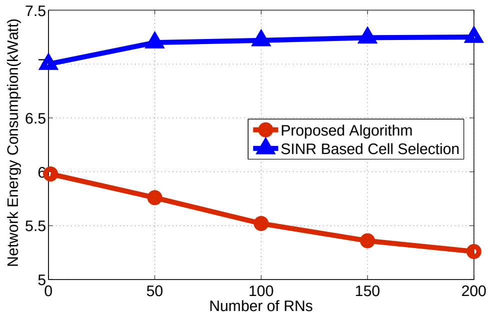

Fig. 3. Network energy consumption against relay density.

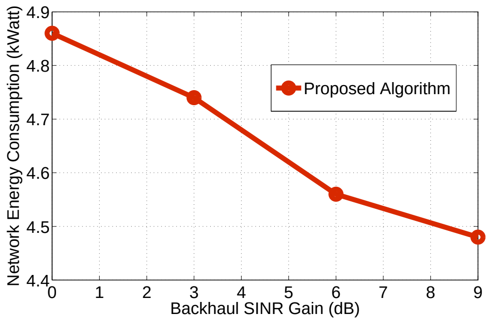

Fig. 5. Network energy consumption against relay backhaul SINR gain.

for $j \notin \tilde{\mathcal{R}}$ and the cell selection criterion makes both $x_{i,j}^{(\mathrm{t}')} = x_{i,j}^{(\mathrm{t})} = 0$ if $i \notin \bar{\mathcal{B}}_j$. Furthermore, we have for any RN j in $\tilde{\mathcal{R}}$:

$$\sum_{i \in \bar{\mathcal{B}}_j} (x_{i,j}^{(\mathrm{t}')} - x_{i,j}^{(\mathrm{t})}) / (b_i \omega_{i,j} (\rho_i^{(\mathrm{t})} + \epsilon)) \leq 0, \tag{11}$$

since only one BS is selected and the BS index i corresponding to $x_{i,j}^{(\mathrm{t}')} = 1$ is the minimizer of $1/b_i\omega_{i,j}(\rho_i^{(\mathrm{t})} + \epsilon)$. This shows that $\mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t}')}) - \mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t})}) \leq \sum_{j \in \tilde{\mathcal{R}}} \sum_{i \in \bar{\mathcal{B}}_j} \frac{r_j^{(\mathrm{k})}(x_{i,j}^{(\mathrm{t}')} - x_{i,j}^{(\mathrm{t})})}{b_i \omega_{i,j} (\rho_i^{(\mathrm{t})} + \epsilon) \log(1+\epsilon^{-1})} \leq 0$ holds. Without details of proof, $\mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t}+1)}) - \mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t}')}) \leq 0$ yields analogously. Therefore, $\mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t}+1)}) \leq \mathrm{U}_\epsilon(\boldsymbol{\rho}^{(\mathrm{t})})$ and the algorithm iteratively reduces the energy consumption of the network.

In Fig. 1, the convergence performance of the algorithm is illustrated, where both the objective and approximation monotonically decrease by iteration steps. Furthermore, it can be observed that the approximation and the real total energy consumption are close to each other and have similar convergence behavior using the proposed algorithm. Note that we choose as for comparison the SINR based cell selection in which the UEs and RNs select nodes with best SINR for data transmission. The SINR based cell selection tends to activate all the BSs, since the UEs are uniformly distributed and are trying to connect to the BSs close to them.

IV. Performance Evaluation

We evaluate the proposed algorithm in a nomadic network with 7 BSs in hexagon layout and with an Inter Site Distance (ISD) of 1000 m. In the coverage of the BSs, 150 UEs and a certain number of nomadic RNs are randomly dropped according to a uniform distribution. In order to avoid severe interference between the RNs, the minimum distance between two nomadic RNs is set to 30 m. The energy consumption for an active BS is assumed to be 1 kWatt, while both BSs and RNs are allocated 10 MHz bandwidth at 2 GHz. Directional antennas are equipped at the BSs and omnidirectional antennas are assumed for the RNs, whereas the maximum transmission powers of BSs and RNs are 46 dBm and 23 dBm, respectively. Furthermore, the radio propagation model is chosen according to the 3GPP recommendations [13] and the noise figure is set to 5 dB at all nodes in the network. The time interval for broadcasting system information and running the distributed algorithm is chosen to be 100 ms. We ignore the time for further signaling procedures and assume cell selection, handover and admission control can be successfully done within this time interval.

First, we choose to evaluate the network performance based on different UE data requirements that vary from 1 Kbps to 1 Mbps (50 nomadic RNs and 10 Watt RN energy consumption). In Fig. 2, it can be seen that the proposed algorithm significantly reduce the energy consumption compared with the SINR based algorithm. In particular in low rate scenarios, around 40% energy savings can be expected. As the average rate requirement of UE increases, the energy saving gain decreases since the BSs are becoming more and more overloaded.

Further evaluations are based on the configurations of the nomadic RNs, including the density of nomadic RNs, the per RN energy consumption and the RN backhaul link SINR gain. These evaluations set up the basic requirements for designing the nomadic network and relay infrastructure in order to achieve performance gain in terms of energy savings.

In Fig. 3, the energy saving performance is depicted for different densities of RNs, where the UE average rate requirements is set to 100 kbps. It can be easily concluded from the figure that higher RN density results in more energy savings by using the proposed algorithm. In contrast, higher RN density leads to slightly more energy consumption by using the SINR based algorithm, since more RNs are activated without switching off any BSs. As the number of RNs increases to 200 from 50, around 10% less energy consumption is required to the support the UEs. The performance improvement is due to the fact that the extra RNs imply a higher possibility of having suitable RNs to redirect data traffics for energy saving purposes. Note that we assume worst-case interference in this study and more RNs mean more interference, and therefore more energy savings can be expected with a high RN density considering the dynamic interference models as in [4], [14], [15].

Fig. 4 depicts the energy saving performance with respect to the per RN energy consumption, where a network with 50 RNs and an average rate requirement of 10 kbps is assumed. Logically for both algorithms, the total energy consumption increases as the per RN energy consumption increases. If each active RN consumes lower than around 10 Watt, corresponding to 1% of the energy consumption of a BS, the energy saving performance is close to the case when RN causes no energy consumption. Note that the energy consumption of a low power node is in practice at the level of 10 Watt, therefore, the concept of nomadic network has the potential to save energy in a realistic network.

At last, we evaluate the network performance considering another important aspect - the RN backhaul performance gain. Since more space is available for designing the antenna of the vehicles, the backhaul link performance gain can be achieved through smart antenna designs or advanced signal processing techniques such as MIMO and interference cancellation. In Fig. 5, we assume that the backhaul SINR gain varies from 0 dB to 9 dB, where 50 RNs are dropped and the average rate requirement is 10 kbps. The backhaul link SINR gain increases the BS coverage on one hand, and reduces the backhaul link resource consumption on the other hand. Hence, it can be seen that 10% more energy savings in a low rate scenario can be achieved if 9 dB the backhaul link gain is assumed.

V. Conclusion

In this paper, we have presented a distributed cell selection and admission control algorithm for energy savings in nomadic relaying networks based on an optimization framework in our previous works. In order to minimize the energy consumption in the nomadic network, the nomadic relays and subsequently the users select cells according to a novel criterion based on both link quality and network measurements. Furthermore, admission control mechanisms are integrated at the base stations and nomadic relay nodes to avoid overloading. We have proved theoretically that the algorithm iteratively reduces the approximation of the total network energy consumption. Simulation results have verified that the proposed algorithm significantly reduces the energy consumption compared with the traditional SINR cell selection algorithm.

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