Energy Benefits of Opportunistic Device-Centric Wireless Networks

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***Abstract*— Device-centric wireless networks, and in particular Multi-hop Cellular Networks (MCN), can improve the capacity and efficiency of wireless networks, and will hence represent a significant element of the 5G ecosystem. Additional gains can be achieved for mobile delay tolerant services when integrating opportunistic networking in device-centric wireless networks. This paper proposes a solution for such integration that is evaluated for the case of 2-hop uplink opportunistic MCN communications. The proposed solution takes into to account the fact that mobile relays might not always be available at the optimum location and time instant, and the fact that sufficient cellular radio resources might not be available when mobile relays want to start forwarding the information towards the base station. The conducted study shows that the proposed scheme can reduce the energy consumption by more than 80% compared to traditional single-hop cellular communications.**

Keywords- Opportunistic networking; device-centric wireless networks; energy efficiency; 5G; D2D

I. INTRODUCTION

5G networks will need to efficiently accommodate the exponential growth of mobile data traffic. One of the potential 5G key enabling technologies to address this challenge will be device-centric wireless networks that evolve devices from mere data sinks to more active nodes that participate in the network management and operation. Device-centric wireless networks include Device-to-Device (D2D) communications and Multi-hop Cellular Networks (MCNs). MCNs leverage the increasing networking capabilities of smart mobile devices to replace single-hop cellular transmissions by multi-hop transmissions using cellular and D2D links. MCNs have been shown to provide significant benefits in terms of Quality of Service (QoS), energy consumption and capacity [1]. Recent studies have also shown that the integration of opportunistic networking into MCNs can also provide significant benefits for mobile delay tolerant services [2]. It is important noting that according to Cisco Visual Networking Index, delay tolerant services (including mobile video, emails, social and messaging applications, and cloud services) represent a significant portion of the mobile data traffic [3]. For example, mobile video will represent 80% of the mobile data traffic in 2019.

Opportunistic networking has been traditionally proposed for disconnected networks that cannot provide real-time end-to-end connectivity. However, there is a growing interest in exploiting opportunistic networking principles in networks that do not suffer frequent disconnections, but that can benefit from opportunistic networking to improve the efficiency of device-centric wireless communications (D2D and MCNs) [4]. In this case, devices might not initiate a transmission (or even establish a connection) if this transmission is not sufficiently efficient, e.g. because of a poor signal quality. Opportunistic networking allows devices to store and carry the information while looking for more efficient conditions to start forwarding the information. By exploiting the data delivery margins offered by delay tolerant services, devices can reduce their energy consumption and increase the capacity without having any impact on the perceived QoS. The first study that analyzed the integration of opportunistic networking and MCNs was presented in [5], where the authors use information about the mobility of relays to derive routing policies that reduce the energy consumption and increase the spatial capacity. The authors presented in [6] an analytical optimization framework for two-hop opportunistic MCN communications where a Source Node (SN) transmits information to a Base Station (BS) using a Mobile Relay (MR). The framework derived the optimum locations at which the D2D (SN to MR) and cellular (MR to BS) transmissions should take place in order to reduce the energy consumption while satisfying the service QoS requirements. The authors extended this framework to consider scenarios where a MR cannot be found when needed at the derived optimum location. In particular, the authors proposed in [7] solutions to find a mobile relay using cellular context information. In particular, one of the solutions in [7] proposes to increase the MR search area around the identified optimum location, while the other solution in [7] allows waiting a given amount of time for a MR to arrive at the derived optimum location.

All these studies showed that the integration of opportunistic networking and MCNs can improve the efficiency of cellular networks. However, they all assumed that MRs would receive the demanded cellular radio resources when they want to start forwarding the information towards the BS. The availability of these cellular resources cannot be guaranteed in scenarios where all users in the cell share the radio resources independently of their transmission mode (i.e. single-hop cellular communication or multi-hop cellular communication). In this context, this paper builds from the authors' previous results in [6-7], and proposes an integration of opportunistic networking and MCNs that takes into account the probabilistic availability of cellular radio resources.

II. OPPORTUNISTIC MCN COMMUNICATIONS MODELS

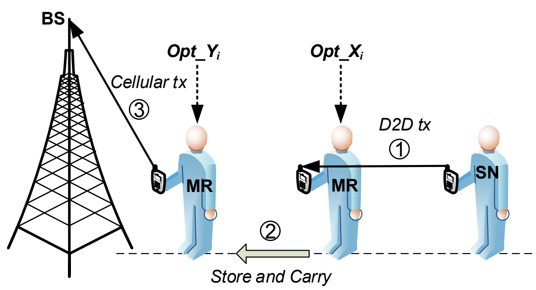


Figure 1. 2-hop opportunistic MCN scenario.

A. Optimization Framework

This study focuses on a 2-hop uplink MCN scenario where a static SN wants to upload a message of size F to a BS before a deadline T (Fig. 1)[1]. To this aim, the SN can first establish a D2D link with a MR that stores and carries the information before forwarding it to the BS. The scenario under evaluation considers that MR moves towards the BS. The opportunistic MCN transmission from SN to the BS needs to be completed before T. The time available to complete the end-to-end transmission (T) has to take into account: 1) the time needed for the D2D transmission from SN to MR (t_{D2D}), 2) the time the MR stores and carries the information (t_{SC}), and 3) the time needed by MR to upload the information to the BS (t_{CELL}). This study uses the optimization framework proposed in [6] to find the times t_{D2D}, t_{SC}, t_{CELL} so that the end-to-end opportunistic MCN transmission satisfies the QoS while minimizing the energy consumption:

$$o.f:\min\left(E_{D2D}\left(t_{D2D}\right)+E_{SC}\left(t_{SC}\right)+E_{CELL}\left(t_{CELL}\right)\right) \tag{1}$$

E_{D2D}, E_{SC} *and* E_{CELL} represent, respectively, the energy consumed at SN and MR during the D2D transmission, the energy consumed at MR during the store and carry process, and the energy consumed at MR following the cellular transmission to the BS. The objective function (1) is defined subject to the requirement that the message of size F is completely received by the BS:

$$TR_{D2D}\left(SN\rightarrow MR\right)\geq F \tag{2}$$

$$TR_{CELL}\left(MR\rightarrow BS\right)\geq F \tag{3}$$

$$t_{D2D}+t_{SC}+t_{CELL}\leq T \tag{4}$$

TR_{D2D} represents the D2D data transmission experienced during the SN-MR transmission, and TR_{CELL} the cellular data transmission in the MR-BS link. The optimization problem defined by eq. (1)-(4) allows identifying for a given location of the SN (SN_i) the optimum configuration of the 2-hop opportunistic MCN transmission that minimizes the energy consumption. This optimum configuration is defined by the time needed to complete the D2D transmission (t_{D2D}), the store and carry process (t_{SC}), and the cellular transmission (t_{CELL}). Deriving these time values is actually equivalent to finding the MR location at which the D2D transmission should start (Opt_X_i), and the MR location at which the cellular transmission should start (Opt_Y_i). Further details about the optimization framework can be found in [6].

1) Energy consumption

The energy consumed in the D2D and cellular transmissions is computed considering that the transmission power (P_{TX}) is established so that it guarantees a power level at the receiver (P_{RX}) sufficient to ensure a successful packet reception. The propagation losses are here modeled using the WINNER (D1.1.2) model for urban scenarios with low antennas height. E_{D2D} and E_{CELL} can be estimated taking into account the energy consumption per bit in the transmitter and receiver electronics (e_{tx} and e_{rx}, respectively) as:

$$E\left(d\right)=\left(e_{rx}+e_{tx}+e(d)\right)\cdot TR \tag{5}$$

where e is equal to P_{TX}/TR. Equation (5) corresponds to Line-Of-Sight (LOS) propagation conditions between the transmitter and the receiver. A similar process can be followed to compute the energy consumption under Non-LOS (NLOS).

This study models the energy consumed by the store and carry process (E_{SC}) following the indications reported in [8]. The storage energy consumption is estimated considering that mobile devices store the received data packets in a storage unit (DRAM), and that the received information is transferred to an internal NAND flash unit to reduce the storage energy consumption [8].

2) Throughput

This study considers, without loss of generality, LTE cellular communications at 2GHz and D2D communications utilizing IEEE 802.11g at 2.4GHz[2]. These radio access technologies were selected due to the availability of the necessary models for the analytical optimization framework. The cellular LTE throughput is computed as a function of the distance (d, in meters) using the model reported in [9]:

$$TR_{CELL}\left(d\right)=r\left(N_{PRB},l_{MCS}\right)\cdot\left(1-p_{BLER}\left(N_{PRB},l_{MCS}\right)\right) \tag{6}$$

[1] The study focuses on 2-hop MCN scenarios due to the increasing complexity of wireless relaying when considering more than two hops and hence the possible diminishing benefits.

[2] 3GPP TR 22.803 considers IEEE 802.11 technologies as well as cellular technologies (e.g. LTE-Direct) for D2D communications.

where $r(N_{PRB}, l_{MCS})$ and $p_{BLER}(N_{PRB}, l_{MCS})$ represent, respectively, the maximum instantaneous data rate and the block error rate as a function of the number of Physical Resource Blocks (N_{PRB}) and the modulation and coding scheme index (l_{MCS}). N_{PRB} has been set to 6 following [10] and the 3GPP TR25.814 guidelines. l_{MCS} follows the 15 available Channel Quality Indicator (CQI) indexes in LTE that are set according to the distance to the BS. The l_{MCS} indexes are mapped to the Transport Block Size (TBS) using the table reported in 3GPP TR36.213, and $r(N_{PRB}, l_{MCS})$ is estimated as TBS/T_{TBS} where T_{TBS} is the TBS duration (equal to 0.5ms in LTE). $p_{BLER}(N_{PRB}, l_{MCS})$ is set equal to 0.1 following the target BLER indications in 3GPP TR36.213. The D2D IEEE 802.11g throughput is computed as a function of the distance (d, in meters) following the model reported in [11]:

$$TR_{D2D}\left(d\right) = DataRate(d)\cdot Eff\cdot\left(1-PER\left(d\right)\right) \tag{7}$$

where *DataRate* is one of the IEEE 802.11g data rates ({54, 48, 36, 24, 18, 12, 9, 6; 11, 5.5, 2, 1} Mbps) and *PER* is the packet error ratio. The *PER* and *DataRate* models have been empirically derived by the authors in [12]. *Eff* represents the IEEE 802.11g channel efficiency, and indicates the effective time that the IEEE 802.11g channel is used to transmit data. *Eff* is estimated using the model reported in [10].

B. *Cellular Radio Resources*

The presented optimization framework was derived assuming that cellular radio resources were always available for the MR at the start of the cellular transmission to the BS. However, cellular radio resources are shared by all users in the cell, and the availability of the demanded resources cannot be guaranteed when MR reaches Opt_Y_i and wants to start the cellular transmission to the BS. This could result in that the cellular MR-BS transmission needs to be delayed until the radio resources are available. This delay could in turn compromise the feasibility to complete the end-to-end MCN transmission to the BS before the service-dependent deadline T. To address this issue, this study proposes to modify the optimization framework by taking into account an estimation of the time a cellular transmission may be delayed (queued) until the demanded radio resources are available. We denote as λ_i the mean arrival rate of cellular connection requests for service i, and with μ_i the mean service time. The arrival rate of cellular connection requests is here modeled with a Poisson distribution, and the service time with an exponential one. This study considers that cellular connection requests are queued whenever there are not sufficient radio resources (PRBs in the case of LTE) to satisfy their demand; this is a possible option for the case of delay tolerant services. The queued requests are served following a FIFO (First In First Out) policy. When a cellular connection is served, it is allocated a number of PRBs during μ_i. This study considers that cellular connections require six PRBs ($N_{PRB}^{Connection}$). The number of cellular connections that are simultaneously served is then:

$$c = \left\lfloor \frac{N_{PRB}^{System}}{N_{PRB}^{Connection}} \right\rfloor \tag{8}$$

where N_{PRB}^{System} represents the total number of PRBs assigned to the LTE base station. Following [13], the probability that a new cellular connection request has to wait to receive the requested cellular radio resources can be computed using the Erlang C formula as:

$$C(c,\rho) = \frac{\dfrac{\rho^c\cdot c}{c!\left(c-\rho\right)}}{\displaystyle\sum_{k=0}^{c-1}\frac{\rho^k}{k!}+\frac{\rho^c\cdot c}{c!\left(c-\rho\right)}} \tag{9}$$

where ρ/c is referred to as the utilization factor, and ρ is equal to $\mu\cdot\lambda$. The distribution function of the time a cellular connection request waits in the system before being served can be estimated as [13]:

$$F_W(t) = 1 - C(c,\rho)\cdot e^{\frac{-(c-\rho)t}{\mu}} \tag{10}$$

Using (10), it is possible to estimate with probability P_w the upper bound of the time (t_w) a cellular connection request needs to wait before being served with $N_{PRB}^{Connection}$ resources:

$$t_w = \frac{-\mu\cdot\ln\left(\dfrac{1-P_w}{C(c,\rho)}\right)}{(c-\rho)} \tag{11}$$

To account for the management of cellular radio resources, this study modifies the opportunistic MCN optimization framework previously presented. In particular, we replace T in eq. (4) by a new deadline T_w=T-t_w that takes into account the time a user has to wait to receive the requested cellular radio resources (t_w). This change results in new values for the MR location at which the D2D transmission should start ($Opt\_X^w{}_i$), and the MR location at which the MR will request to establish the cellular connection with the BS ($Opt\_Y^w{}_i$). The MR request will be served before t_w seconds with probability P_w; the exact moment at which the request is served depends on the actual cell load. This new framework still guarantees that the end-to-end opportunistic MCN transmission will be completed before the service-dependent deadline T.

C. *Space-dependent Opportunistic Forwarding*

The original optimization framework and its modified version in Section II.B assume that an MR can be found when needed at the derived Opt_X_i or $Opt\_X^w{}_i$ locations. This might not always feasible in real deployments. To address this constraint, this study adopts the AREA opportunistic forwarding scheme proposed in [7]. This scheme increases the search area where to look for potential MRs around the identified optimum location. The MR search area is computed using cellular context information, in particular the spatial density and the distribution of nodes within the cell. The original AREA proposal was built from the optimization framework presented in Section II.A. AREA is here adapted to the modified optimization framework (Section II.B) that takes into account the time a cellular transmission may be queued until the demanded cellular radio resources are available.

The AREA adaptation estimates the probability to find at least one MR around $Opt\_X^w_i$ when mobile nodes are uniformly distributed in a cell using a Poisson distribution:

$$P_{Opt\_X_i^w} = P\left(x > 0; \frac{\kappa}{R} \cdot \phi\right) = 1 - \exp\left(-\frac{\kappa}{R}\phi\right), \quad \forall Opt\_X_i^w \in (1,..., R) \tag{12}$$

where k/R is the average spatial density of mobile devices within the cell of radius R, and Ø represents the diameter of the MR search area (equal to $2r$). The radius r that guarantees with probability δ the presence of at least one MR around $Opt\_X^w_i$ can be computed as:

$$r = \frac{R \cdot \ln(1-\delta)}{-2 \cdot \kappa} \quad iff\ \exists\, Y'_i = \underset{\forall X'_i \in o(Opt\_X_i^w, r)}{\arg\min} \left(\vartheta(...)\right) \tag{13}$$

In addition to guaranteeing with probability δ the presence of at least one MR, the search area radius (13) requires the optimization framework (represented by □ in (13)) to provide the location at which the MR has to start the cellular transmission (Y'_i) for every possible location of the MR (X'_i) within the search area. If these conditions are not met, SN will transmit the information directly to the BS using a traditional single-hop cellular connection. Eq. (12) and (13) have been obtained considering a uniform distribution of nodes within the cell. The same expressions can be used for non-uniform distributions in scenarios where the cell is divided into rings and the spatial density of users per ring is known. This is actually the case for LTE that divides cells into concentric rings where users utilize different transmission modes. In this context, the radius r around $Opt\_X^w_i$ can be computed for non-uniform distributions of nodes within the cell replacing k/R in (13) by φ_i/l_r^i. φ_i represents the average number of nodes in the ring i where $Opt\_X^w_i$ is situated, and l_r^i the ring length.

III. Performance Evaluation

This section is aimed at demonstrating the benefits of opportunistic MCN communications with respect to single-hop cellular communications. The optimum configuration (referred to as 'Optimum') presented in Section II.A is used as benchmark. This configuration assumes that an MR can be found when needed at Opt_X_i, and that the cellular resources are available when MR initiates the cellular transmission at Opt_Y_i. The alternative optimum configuration that takes into account the time a cellular connection request might have to wait until radio resources are available (Section II.B) is referred to as 'Opt-PRBs'. 'Optimum' and 'Opt-PRBs' consider that an MR can always be found at Opt_X_i and $Opt\_X^w_i$ respectively. 'AREA-PRBs' (Section II.C) does not make this assumption, and increases the MR search around $Opt\_X^w_i$.. 'AREA-PRBs' also takes into account the time a cellular connection request might have to wait until radio resources are available.

The schemes are evaluated in an LTE network with N_{PRB}^{System} =25 (i.e. 5MHz bandwidth system), and a cell radius of 1Km. MRs are considered to be in line with the SN, and move towards the BS at a speed of v=2m/s. We consider a non-uniform distribution of nodes within the cell, with higher spatial densities close to BS. The average spatial density of nodes within the cell is 0.075MRs/m. The file that SN needs to upload to the BS has a nominal size of F=10Mb, and it has to be transmitted to the BS before the deadline T=60s. The energy consumed at mobile devices due to the store and carry process has been obtained from [8]. Following [5], the power reception threshold P_{RX} is equal to -62dBm, and the energy consumed per bit in the transmitter/receiver electronics has been set as $e_{tx}=e_{rx}=50\cdot10^{-9}$J/b. The cell load is varied by modifying the arrival rate of cellular connection requests following a Poisson process with mean $\lambda=\{1/3,\ 2/7,\ 1/4\}s^{-1}$. The service time is considered to be exponentially distributed with mean μ=10s.[3] The 'AREA-PRBs' scheme is evaluated with the probability δ equal to 0.9 and the cellular context information (spatial density of users) being provided per ring -LTE divides cells into concentric rings based on parameters such as the signal strength or CQI. The results presented in this section were obtained for a large number of experiments (minimum of 300) in order to ensure that the standard error of the mean is always below 0.01.

The 'Opt-PRBs' scheme takes into account the cell load information to identify the location at which MR should request cellular resources to initiate the forwarding to the BS. Fig. 2 represents for this scheme, the distribution of the locations at which MR initiates the cellular transmission to the BS after the MR request for cellular resources is served. These locations are represented as a function of the distance between MR and BS when SN is located 800m away from the BS. Fig. 2 also represents using vertical lines the location at which MR requests the cellular resources (Opt_Y^w) for different values of P_w, and the optimum location at which the MR should start the cellular transmission (Opt_Y) following the 'Optimum' scheme. The figure shows that Opt_Y^w increases with P_w. The considered P_w values result in cellular waiting times (t_w) of 5s, 14s and 37s. Fig. 2 shows that a high percentage of cellular connection requests are served at Opt_Y^w for all P_w values. Fig. 2 also shows that decreasing P_w values increase the percentage of cellular transmissions from MR to the BS that are initiated closer to Opt_Y. All MR-BS cellular transmissions that are initiated at a distance to the BS smaller than Opt_Y will require more than T seconds to complete the end-to-end MCN transmission.

[3] This value corresponds to the call duration in [14] to model streaming video traffic.

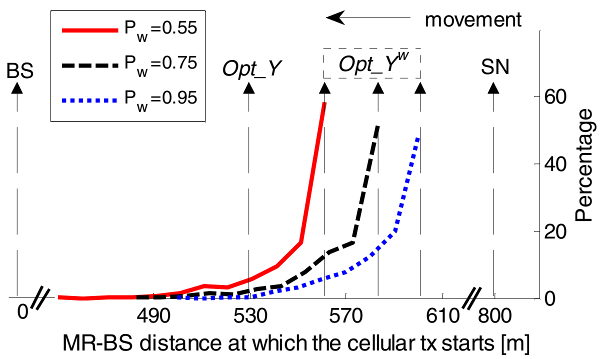
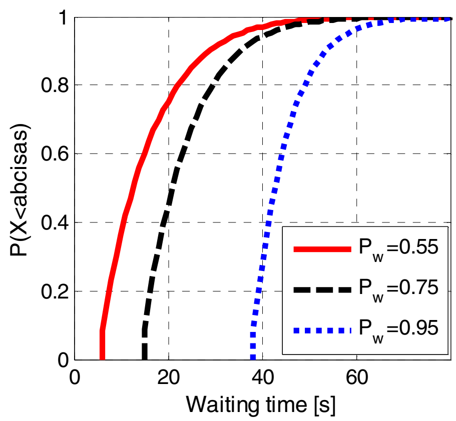


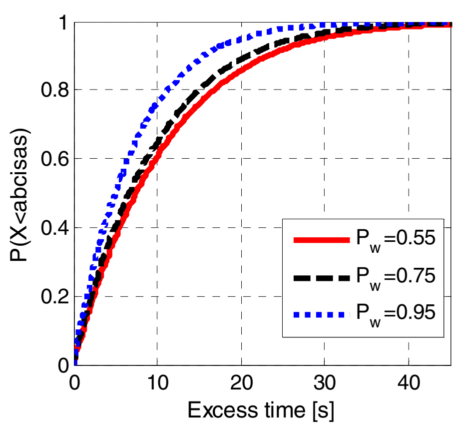
Figure 2. Distribution of the locations at which MR initiates the cellular transmission to the BS (λ=1/3s-1) for the 'Opt-PRBs' scheme.

TABLE I. PERCENTAGE OF MCN TRANSMISSIONS THAT WERE NOT COMPLETED BEFORE THE DEADLINTE T

	λ=1/3s^{-1}			λ=2/7 s^{-1}			λ=1/4 s^{-1}		
Technique \ P$_w$	**0.55**	**0.75**	**0.95**	**0.55**	**0.75**	**0.95**	**0.55**	**0.75**	**0.95**
Opt-PRBs	38.0	15.5	0.5	38.9	21.6	3.0	40.0	23.4	5.5
AREA-PRBs	35.6	14.5	0.5	35.6	20.3	2.8	38.5	22.0	5



a) Waiting time



b) Excess time

Figure 3. MCN transmissions that were not completed before T using the 'Opt-PRBs' scheme (λ=1/3s-1).

Table I reports the percentage of opportunistic MCN transmissions that were not completed before the deadline T for the scenario illustrated in Fig. 2. Table I shows that on average 38% of the transmissions required more than T seconds when 'Opt-PRBs' was set up with P_w=0.55. This percentage decreases to 15.5% and 0.5% when P_w increases to 0.75 and 0.95, respectively. This is the case because when P_w is reduced, 'Opt-PRBs' frequently underestimates the time that the cellular connection requests must wait before being assigned the requested cellular resources. Fig. 3.a illustrates, for the MCN transmissions that were not completed before T, the time the MR cellular connection requests had to wait before being assigned the demanded cellular radio resources. This figure shows that when P_w is set equal to 0.95, only the cellular connection requests that had to wait a very long time (higher than t_w=37s) before being served could not complete the transmission before T. On the other hand, Fig. 3.a shows that with P_w=0.55, users with waiting times as low as 6s could not complete their MCN transmission before T. Fig. 3.b represents the excess time, or the time by which the MCN transmissions that were not completed before the deadline T exceeded this deadline. The figure shows that increasing the P_w parameter to 0.95 reduces the excess time.

TABLE II. AVERAGE REDUCTION (IN %) OF THE TOTAL ENERGY CONSUMPTION COMPARED TO SINGLE-HOP CELLULAR COMMUNICATIONS.

	λ = 1/3s^{-1}			λ = 2/7s^{-1}			λ = 1/4s^{-1}		
Technique \ P$_w$	**0.55**	**0.75**	**0.95**	**0.55**	**0.75**	**0.95**	**0.55**	**0.75**	**0.95**
Opt-PRBs	93.7	92.6	88.6	93.9	93.4	91.5	93.9	93.7	92.5
AREA-PRBs	85.7	86.6	79.0	84.8	85.3	84.1	84.7	85.5	85.5
Optimum	94.0								

Table II reports the average reduction of the total energy consumption achieved by each one of the opportunistic MCN schemes under evaluation compared to single-hop cellular communications. As expected, the major energy gains are achieved with the optimum framework, although its feasibility is seriously compromised by the need to find an MR at the identified location and time instant, and the need to guarantee the availability of cellular radio resources when MR wants to start forwarding the information towards the BS. 'Opt-PRBs' takes into account the availability of cellular radio resources to configure the opportunistic MCN transmission, and therefore does not achieve the same energy gains as the optimum configuration. These gains can be close to those obtained with the optimum configuration with low values of the P_w parameter. However, this is obtained at the expense of a higher percentage of opportunistic MCN transmissions that are not completed before the deadline T (Table I) and higher values of the excess time (Fig. 3). If 'Opt-PRBs' is configured with P_w=0.95, only a low percentage of connections do not complete their transmission before T (maximum of 5.5% when λ=1/4s^{-1}), and significant energy gains are still achieved compared to traditional single-hop cellular communications. The 'Optimum' and

'Opt-PRBs' configurations assume that an MR can always be found at the identified optimum location and time instant. This assumption can be unrealistic, and is addressed by 'AREA-PRBs'. This scheme increases the MR search around the optimum MR location and takes into account the availability of cellular radio resources. Table II shows that 'AREA-PRBs' is still capable to achieve significant energy gains compared to traditional single-hop cellular communications (average reduction values above 79%). The small degradation observed with 'AREA-PRBs' compared to 'Opt-PRBs' is due to the need to select MRs that are not exactly at the optimum location, and the fact that 5% of connections did not find any node within the MR search area and the SN had to transmit the information directly to the BS using single-hop cellular communications. Table I and Table II show that the effect of P_w on 'AREA-PRBs' is similar to that observed for 'Opt-PRBs'.

The energy gains achieved across a cell are illustrated in Fig. 4. Fig. 4 represents the energy efficiency as a function of the distance between SN and BS for P_w=0.95 and $\lambda=1/3s^{-1}$. The energy efficiency is computed, following the ETSI ES 203 228 standard, as the ratio between the delivered data and the energy consumed for such delivery. The figure shows that the integration of opportunistic networking and MCN can achieve significant energy gains compared to traditional single-hop cellular communications from distances higher than 150m. The major gains are obtained with the optimum (but unrealistic) configurations. However, the realistic integration of opportunistic networking and MCN ('AREA-PRBs') can also significantly improve the energy efficiency compared to single-hop cellular communications. For example, when SN is located 300m away to the BS, 'AREA-PRBs' increases the energy efficiency by 320% with respect to single-hop cellular communications. This value increases above 400% for SN distances to the BS higher than 700m.

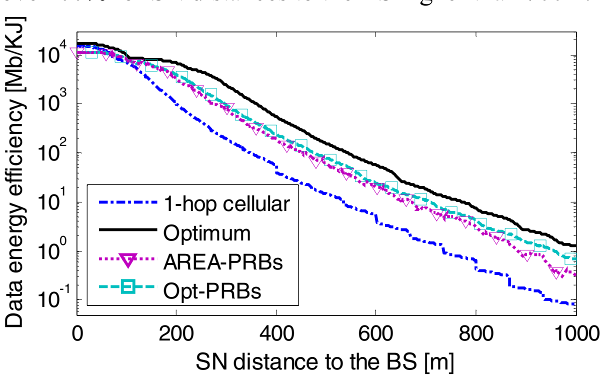


Figure 4. Energy efficiency (P_w=0.95, $\lambda=1/3s^{-1}$).

IV. Conclusions

This paper has proposed a solution to integrate opportunistic networking and MCNs under realistic conditions. The proposed solution accounts for the fact that MRs might not always be available at the optimum location and time instant, and the fact that sufficient cellular radio resources might not be available when MRs want to start forwarding the information towards the BS. The obtained results demonstrate that the proposed scheme can reduce the energy consumption by more than 80% compared to traditional single-hop cellular communications for delay tolerant services. These significant energy gains, in line with the energy efficiency objectives established for 5G, are achieved without actually degrading the service QoS requirements.

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