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Conference Paper · January 2011

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Energy Efficient Fair Content Distribution over LTE Networks using Bluetooth Piconets

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Abstract— **Energy efficient content distribution with mobile-to-mobile cooperation is considered. The distribution method is based on long range transmission from a base station and on short range cooperation between mobile terminals. Long range communication is assumed over an LTE network whereas Bluetooth is considered on the short range. A low complexity energy-efficient content distribution approach is presented and compared to the optimal solution. Results show that the proposed approach leads to more fairness than the optimal solution, at the expense of a slight performance degradation in terms of energy savings. However, significant energy savings are obtained compared to the scenario without mobile-to-mobile cooperation. Thus, the use of Bluetooth in cooperative short range communications can lead to increased energy efficiency for mobile terminals.**

I. INTRODUCTION

Major challenges towards the development of next generation 4G wireless networks include fulfilling the foreseeable increase in power demand of future mobile terminals (MTs) in addition to meeting the high throughput and low latency requirements of emerging multimedia services. The evolution of MTs with multiple wireless interfaces is expected to play a central role in the design of next generation wireless networks where the throughput and power limitations of a given wireless technology can be overcome by allowing cooperation among MTs over other wireless interfaces [1], [2]. This results in a heterogeneous network architecture with MTs that actively use two wireless interfaces: one to communicate with the base station (BS) over a long-range (LR) wireless technology (e.g., UMTS/HSPA, WiMAX, or LTE) and one to communicate with other MTs over a short-range (SR) wireless technology (e.g., Bluetooth or WLAN).

Studies show that the high energy consumption of battery-operated MTs will be one of the main limiting factors for future wireless communication systems. In order to tackle this limitation, mechanisms to reduce energy consumption appear extensively in the literature, e.g. see [1], [3]. In [1], a cooperative network architecture composed of an LR link technology and an SR link technology is presented in order to reduce energy consumption among MTs during real-time video streaming. Results show promising opportunities to decrease the total energy consumed by increasing the number of collaborative MTs. Strategies to improve the performance of Bluetooth peer-to-peer communications are presented in [2], for the purpose of cooperatively downloading and sharing content from digital billboards between Bluetooth peers. In [4], preliminary experimental analysis for a collaborative video streaming architecture using test bed implementation is presented. A group of MTs interested in the same video are connected to a WLAN access point through which they pull one of the video descriptions that they share with other MTs using their Bluetooth interface. This collaborative scheme proved to be more energy efficient than pulling all the video over the WLAN interface.

Data sub-stream distribution and energy consumption are studied in an optimized way in [5], where energy minimization with mobile-to-mobile (M2M) collaboration is formulated and solved using integer linear programming (ILP), both in the cases of unicasting and multicasting. The optimal solution of [5] showed that the whole data stream is sent to a single MT on the LR link, and that MT is responsible for the distribution of the data on the SR, whether via unicasting or multicasting. Hence, although this solution leads to energy minimization in the network, it is unfair towards the MT selected for data distribution.

In this paper, we deal with the problem of energy efficient content distribution by presenting a fair approach in terms of MT energy consumption. The proposed approach consists of sending equal parts of the content on the LR to each of the MTs. Then the MTs distribute the content on the SR links. The simulation setup considered is based on state-of-the-art wireless communication systems: LTE is used on the LR BS-MT links and Bluetooth is used for unicasting on the SR MT-MT links.

This paper is organized as follows. Section II presents an overview of the energy minimization formulation. In Section III, the proposed low-complexity fair approach is presented. Simulation results are presented and discussed in Section IV. Practical implementation aspects and research directions for further investigation are discussed in Section V. Finally, conclusions are drawn in Section VI.

This work was made possible by an NPRP grant from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

II. SYSTEM MODEL

This section presents the system model and summarizes the problem formulation for minimizing the total consumed energy. The system model is depicted in Figure 1. The design consists of a number K of cooperating MTs in the range of a BS. The BS is connected via wired LAN to the server that holds the content. Terminals can communicate with each other over SR links. In a traditional setup, the server either separately streams the complete content to each requesting MT or multicasts the content once to all requesting MTs. In both cases, the communication interface of each MT remains active for the whole reception duration, which depends on the length of the content. This results in high energy consumption due to the required processing during data reception.

In this work, we assume the establishment of an M2M network between the MTs over SR wireless links that are more energy-efficient than the LR wireless link, in terms of the total energy consumed in the network for content distribution. In this scheme, the content is divided into N parts. If K MTs are requesting the content, then, each will be receiving a subset of the N data parts from the server. Over the SR wireless links, each MT receives the remaining data subsets from the other cooperating MTs in the M2M network. Being exchanged over an energy-efficient SR wireless technology, the SR exchanged subsets require lower reception power at the communication interface of the MTs. However, an additional overhead in this case is that each MT needs to spend additional energy to transmit its received data subset to the other cooperating MTs.

LTE communications are considered on the LR BS-MT links. LTE will stretch the performance of 3G technology, in order to meet user expectations in a 10-year perspective and beyond [6]. The objectives of LTE include reduced latency, higher user data rates, improved system capacity and coverage, and reduced overall cost for the operator. Data rates of 100 Mbps in the downlink and 50 Mbps in the uplink are expected. To meet these requirements, orthogonal frequency division multiple access (OFDMA) based on OFDM is the key technique of LTE because it has immunity to inter-symbol interference and frequency selective fading [6].

Bluetooth communications are considered on the SR MT-MT links. Bluetooth is a low-cost, low-power and short-range communication technology. It operates in the 2.45 GHz Industrial, Scientific, and Medical (ISM) band. It performs frequency hopping over 79 channels at a speed of 1600 times per second, with the bandwidth of each channel being 1 MHz [7]. In a Bluetooth network, a piconet is formed of one Master and up to seven slaves. A scatternet is a network that consists of more than one piconet. A bridge is a device that joins two or more piconets [7]. In this paper, unicasting is assumed, since with Bluetooth multicasting consists of sending the same data on several unicasting links [8]. Several attempts in the literature are investigating modifications to the standard in order to allow energy efficient multicasting with Bluetooth, e.g., see [8], [9].

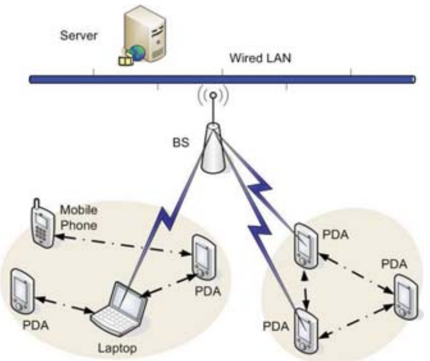

Fig. 1. General system model.

A. Energy Formulation

We denote by S_T the size of the content divided into N parts, K the number of requesting MTs, x_k the number of parts received by MT k over the LR link, $R_{L,k}$ the transmission rate on the LR links from the BS to MT k, $R_{S,kj}$ the transmission rate on the SR links from MT k to MT j, P_{Rx} the power consumed by the MT during reception, and P_{Tx} the power consumed by the MT during transmission. P_{Rx} and P_{Tx} are expressed in Watts, and their multiplication by the time (in seconds) needed for reception and transmission, respectively, yields the energy consumption in Joules. The total energy consumed by MT k is:

$$E_k = \frac{x_k \cdot S_T}{N \cdot R_{L,k}} P_{\mathrm{Rx}} + \frac{x_k \cdot S_T}{N} P_{\mathrm{Tx}} \sum_{j=1, j\neq k}^{K} \frac{1}{R_{S,kj}} + \frac{S_T}{N} P_{\mathrm{Rx}} \sum_{j=1, j\neq k}^{K} \frac{x_j}{R_{S,jk}} \quad (1)$$

In (1), the first term corresponds to energy consumption while receiving the content on the LR link, the second corresponds to transmitting the content on the SR links, and the third corresponds to receiving the other content parts from the other MTs on the SR links.

It should be noted that P_{Rx} and P_{Tx} correspond to the power consumed by the MT, i.e., drained from its battery, during reception and transmission, respectively. They are not to be confused with P_r and P_t, the respective receive and transmit powers over the air. To enforce the distinction, we will use Joules/sec as the unit for P_{Rx} and P_{Tx}, whereas we will keep using Watts as the measurement unit for P_r and P_t.

The total energy consumed in the network with M2M cooperation is given by:

$$E_{\mathrm{coop}} = \sum_{k=1}^{K} E_k \quad (2)$$

The total energy consumption spent when no cooperation takes place is:

$$E_{\mathrm{No-coop}} = S_T \cdot P_{\mathrm{Rx}} \sum_{k=1}^{K} \frac{1}{R_{L,k}} \quad (3)$$

The normalized energy consumption η can be calculated as follows:

$$\eta = \frac{E_{\text{coop}}}{E_{\text{No-coop}}} \tag{4}$$

The value of η indicates whether the cooperation is beneficial in terms of energy consumption or not; if $\eta < 1$, then the cooperation results in a gain of energy consumption while $\eta > 1$ reflects a non-beneficial cooperation.

B. Channel Model

The channels on the LR and SR links are modeled by pathloss and shadowing. Thus, the channel gain can be expressed by a pathloss model as in [10]:

$$H(dB) = \underbrace{10\log_{10}\kappa - 10\nu \cdot \log_{10}\frac{d}{d_0}}_{\text{distance based pathloss}} + \underbrace{h_{\text{dB}}}_{\text{random variable}} \tag{5}$$

where κ is a unitless constant which depends on the antenna characteristics and the average channel attenuation, ν is the path loss exponent, d_0 is a reference distance, d is the distance where the received power is calculated, and h is a Gaussian random variable representing shadowing or slow fading having a zero mean and a variance $\sigma^2_{h_{\text{dB}}}$. This channel model corresponds to a low mobility or quasi-static scenario where fast fading is averaged out, and where M2M communication can be efficiently performed [5].

III. PROPOSED APPROACH

The optimal solution consists of sending all the data to a single MT, and this MT is in charge of distributing the data to all other MTs on the SR links [5]. Although this leads to significant energy savings in the network, it is unfair for the selected MT in terms of energy consumption. Therefore, a low-complexity fair approach is presented in this section. It consists of sending the data in equal parts on the LR to all cooperating MTs. Then each MT should send the data it received on the LR to the other MTs on the SR links. Although this approach treats all MTs equally and is thus suboptimal in terms of network energy minimization, it is shown in Section IV that it still leads to considerable energy savings while ensuring an increased fairness between MTs.

A. LTE Communication on the Long Range

LTE communication is considered on the LR BS-MT links. In LTE, the available spectrum is divided into resource blocks (RB) consisting of 12 adjacent subcarriers, allocated in a 0.5 ms time slot. The shortest assignment unit consists of two consecutive slots, i.e., for a duration of 1 ms, which is the duration of one transmission time interval (TTI) [11], [12], [13].

A total bandwidth of $B_{\text{tot}} = 5$ MHz, subdivided into $N_{\text{RB}} = 25$ RBs of 12 subcarriers each is assumed. Each subcarrier has a bandwidth of $B_{\text{sub}} = 15$ kHz, such that the bandwidth of an RB is $B_{\text{RB}} = 180$ kHz [12]. On the LR, allocation is performed on the basis of one RB per user. This allows a fair comparison with the non-cooperative scenario, where we consider that each MT is allocated one RB over which the BS sends the data. The BS power is assumed to be subdivided equally among the RBs. The total BS downlink transmit power is considered to be 5 Watts.

The data rates over LR LTE links can be computed as follows: given for each MT the transmit power $P_{k,i}$ that the BS is using to transmit to MT k over subcarrier i, the channel gain $H_{k,i}$ of MT k over subcarrier i, and the thermal noise power σ^2, the received signal-to-noise ratio (SNR) $\gamma_{k,i}$ of MT k over subcarrier i can be calculated following $\gamma_{k,i} = \frac{P_{k,i}H_{k,i}}{\sigma^2}$. Given the target bit error rate P_e and the SNR, the achievable rate on the LR link of MT k can be calculated according to the following:

$$R_k = \sum_{i \in \mathcal{I}_{\text{sub},k}} B_{\text{sub}} \cdot \log_2(1 + \beta\gamma_{k,i}) \tag{6}$$

In (6), $\mathcal{I}_{\text{sub},k}$ represents the set of subcarriers in the RB allocated to MT k, and β is called the SNR gap. It indicates the difference between the SNR needed to achieve a certain data transmission rate for a practical M-QAM system and the theoretical limit (Shannon capacity) [10], [14]. It is given by: $\beta = \frac{-1.5}{\ln(5P_e)}$.

B. Bluetooth Communication on the Short Range

Bluetooth transmission supports two modulation modes: a mandatory mode, the Basic Rate (BR), and an optional mode, called Enhanced Data Rate (EDR). EDR uses phase shift keying (PSK) modulation and has two variants: $\pi/4$ differential quadrature PSK ($\pi/4$-DQPSK) and 8 differential PSK (8DPSK) [7]. The 1 MHz Bluetooth channel bandwidth corresponds to 1 Mbps gross air data rate using BR, to 2 Mbps using EDR with $\pi/4$-DQPSK modulation, and to 3 Mbps using EDR with 8DPSK. However, the actual rates achieved are 721.2 kbps with BR and 2.1 Mbps with EDR [7]. In the SR communications between MTs, we consider scenarios where either BR or EDR is used. Bluetooth devices with Power Class 1 are considered, i.e., the maximum MT transmit power on the SR is 100 mW [7].

Although Bluetooth supports 79 channels, communications between two devices at a given instant occur over one channel. Hence, there is no simultaneous transmission over several subcarriers as in LTE. It should be noted that, in a low mobility scenario with users located in a close proximity, as in the scenario investigated in Section IV, Class 1 Bluetooth devices can generally always achieve the full 721.2 kbps with BR and the 2.1 Mbps with EDR. For this reason, power control is required in the Bluetooth standard [7], such that the MTs transmit at the power necessary to achieve the BR or EDR rates. Thus, transmission at the maximum power of 100 mW is not actually performed unless necessary.

C. Fairness Analysis: Jain's Fairness Index

The Jain's fairness index was derived in [15]. It is widely used to assess fairness in resource allocation in wireless communications, mainly in terms of achievable data rates [16]. In this paper, the interest is in the consumed energy, and the fairness achieved with the proposed approach by allowing content distribution with a fair energy consumption between the different MTs. The application of Jain's fairness index to energy consumption can be written as:

$$J = \frac{\left(\sum_{k=1}^{K} E_k\right)^2}{K \sum_{k=1}^{K} E_k^2} \tag{7}$$

A completely fair solution (equal energy consumption by all MTs) will lead to having $J = 1$. The most unfair solution will lead to a value of $J = 1/K$, and corresponds to the situation where all the energy consumption occurs at a single MT.

IV. RESULTS AND DISCUSSION

This section presents the simulation results obtained by comparing the proposed approach to the optimal approach and to the non-cooperative approach, in terms of energy consumption and fairness.

A. Simulation Model

The solution to the optimal problem of Section II-A is obtained using the method of [5], and the results are compared to the low complexity protocol proposed in Section III. We consider a file of size $S_T = 1$ Mbits, subdivided into 25 parts, to be transmitted to all requesting MTs. LTE is used on the LR using the parameters of Section III-A, and Bluetooth is considered on the SR using the scenario of Section III-B. The simulation parameters are presented in Table I. Channel parameters are obtained from [17], whereas energy consumption parameters are taken as in [5].

TABLE I

SIMULATION PARAMETERS

Parameter	Value
κ	-128.1 dB
ν	3.76
d_0	1000 m
$\sigma_{h_{\mathrm{dB}}}$	8 dB
P_{Tx}	1.015 Joules/s
P_{Rx}	0.66 Joules/s

B. Snapshot Results

In this section, snapshot results are presented in order to show the behavior of the optimal solution and of the fair approach at a given shadowing realization. Averaged results are shown in Section IV-C. We consider $K = 5$ MTs located at a constant distance $d_{\mathrm{LR}} = 1$ km from the BS, with a 2 m separation between an MT and its neighbor MTs. We present a snapshot result corresponding to a single shadowing realization. EDR transmission is assumed. Fig. 2 shows the energy consumed by each of the five MTs at a given snapshot, whereas Fig. 3 shows the number of parts allocated to each MT. It can be clearly seen form Fig. 3 that the optimal approach allocates all data parts to a single MT, whereas the proposed approach leads to equal allocation between MTs. Fig. 2 shows that the energy for the last MT with the optimal solution exceeds its consumed energy in the non-cooperative case. However, the energy for all other MTs is significantly reduced. The fair approach leads to energy savings for all MTs, although the total energy consumed is higher than in the optimal case.

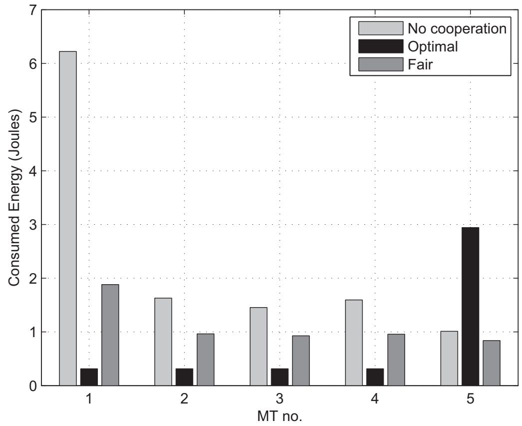

Fig. 2. Energy consumption of each MT at a given snapshot.

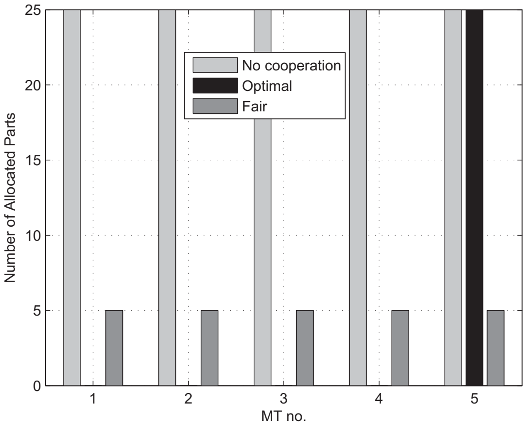

Fig. 3. Number of parts allocated to each MT at a given snapshot.

C. Average Results

In this section, average results are presented, where the averaging is over 10,000 iterations with lognormal shadowing. MTs are assumed to be uniformly distributed in a rectangular area of size 5×5 m, whose origin is at a distance d_{LR} from the central BS. The normalized energy consumption results are shown in Fig. 4 for BR and EDR in addition to different values of the long range distance.

Fig. 4 shows that the optimal solution consisting of greedy minimization of the total energy in the network leads to better results than the proposed fair energy minimization. However, the use of the fair approach still allows achieving significant savings compared to the non-cooperative scenario, since the value of η is significantly smaller than one. As expected, the use of BR leads to higher energy consumption than EDR, since the reduced rate requires longer transmission and reception times in order to transfer the data parts. Varying

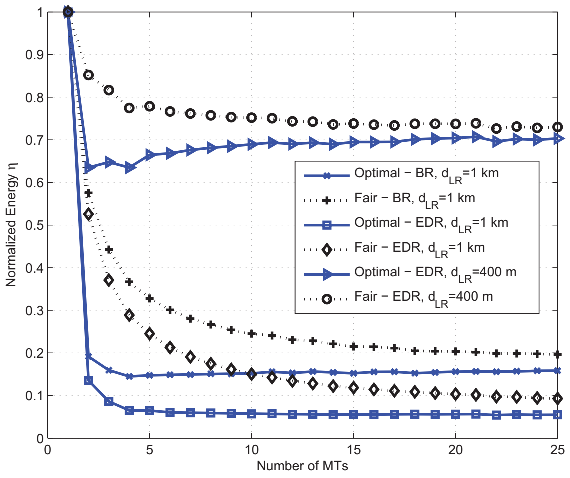

Fig. 4. Normalized energy consumption vs. the number of MTs.

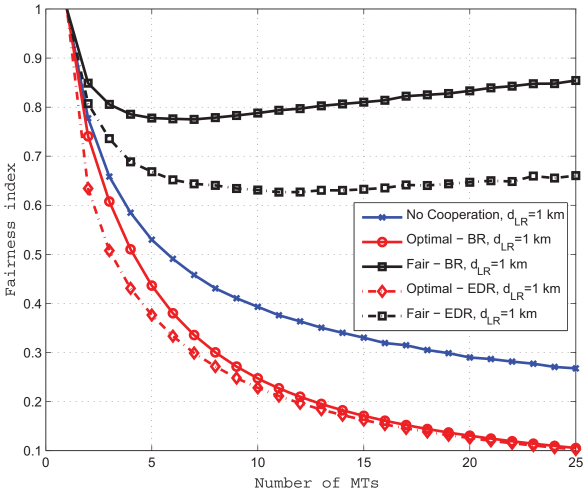

Fig. 5. Jain's Fairness index vs. the number of MTs.

d_{LR} from 1000 m to 400 m leads to a significant increase in normalized energy. The reason is not an increased energy consumption with the proposed approach, but a reduced consumption on the LR link in both the cooperative and non-cooperative case, due to the the significantly reduced LR distance, while the consumption on the SR in the cooperative case is the same, which leads to an increase in the ratio η.

The results of Fig. 4 do not show the enhanced fairness obtained by the proposed low complexity fair approach. Fig. 5 shows the results of the Jain's fairness index. Clearly, the plots of the optimal solution keep decreasing with the number of users. This is due to the fact that the optimal solution requires that a single MT receives all the data on the LR and distributes it on the SR. In fact, this solution is more unfair than the non-cooperative case, since in the latter all MTs receive the data on the LR. However, their energy consumption varies due to their channel variations on the BS-MT link. In other words, data is transferred faster to a user with good channel gain (and hence with less energy consumption) compared to a user with bad channel gain, where a low rate is achievable and more energy is consumed to receive the data. With the fair approach, the fairness index is significantly higher than the optimal and the non-cooperative scenarios. In addition, the fairness plots of the fair approach present a slight increase in the fairness index when the number of MTs increases. In fact, as the number of MTs increases, the share transmitted to each MT on the LR is reduced, which reduces its LR energy consumption. However, the energy consumption on the SR is comparable between the different MTs due to the short distances and hence the high achievable rates on the SR Bluetooth links. Consequently, this leads to a more uniform energy consumption which leads to a higher fairness index.

It should be noted that the optimal plots of Fig. 4 converge to a stable value when the number of cooperating MTs exceeds five. With the proposed fair approach, convergence is slower, but most of the energy saving benefits can be achieved with eight cooperating MTs, i.e., the size of a single Bluetooth piconet. This is an interesting result, since it means that each group of eight MTs can form an independent piconet, and the BS can subdivide the content into eight parts, sending a part to each different member of a given piconet. The SR distribution can be performed independently within each piconet, without the need to have bridges and scatternets.

V. PRACTICAL IMPLEMENTATION ISSUES AND FUTURE RESEARCH DIRECTIONS

In this section, practical implementation issues are discussed and directions for future investigation are outlined.

A. *Piconets and MT Clustering*

In the simulations of Section IV-C, we considered scenarios with more than eight users (maximum piconet size). But scatternets were not considered, since in this case a bridge should be used between two piconets and will have to receive the data from MTs on the first piconet and transmit it to the second piconet, which corresponds to multihop communications. Since multihop communications are not considered in the model of Section II, it is assumed that each user communicates its data parts over the SR links to devices within its piconet via unicasting, then forms a piconet with other devices if needed (i.e., if more than eight devices are communicating) in order to send the data to the new devices via unicasting, and so on, until all MTs receive the data. It should be noted that the energy overhead to form piconets is not taken into account. However, interestingly, the results of Section IV-C show that most of the energy savings can be achieved within a single piconet. This leads to the conclusion that efficient energy savings can be achieved by M2M cooperation within each piconet independently. Thus, it would be interesting to investigate clustering of MTs into piconets, where efficient clustering techniques could be derived in order to ensure optimized MT grouping, for the purpose of energy minimization while ensuring efficient content distribution. These techniques can be based, for example, on coalitional game theroy [18].

B. Multicasting vs. Unicasting

In [5], it was shown that with the optimal approach, energy consumption with multicasting is less than with unicasting. With multicasting, content is transmitted once by each MT on the SR. However, the lowest rate achievable on the SR links should be used, so that all MTs receive correctly the multicasted data. However, the reduction in the number of SR transmissions with multicasting leads to energy savings compared to unicasting. Thus, the use of energy efficient Bluetooth multicasting algorithms with the proposed approach is an interesting topic for future investigation.

C. Dynamic LTE Resource Allocation

In this paper, LTE resource allocation was performed on the basis of one RB per MT, in order to perform a fair comparison with the non-cooperative scenario, where the content was assumed to be sent simultaneously to all MTs over the available LR LTE resources. After showing the importance of short range communications in reducing the total energy consumption and demonstrating the superiority of the proposed approach over the non-cooperative case, a natural extension would be to consider dynamic resource allocation in LTE. In this case, scheduling algorithms for allocating the RBs and the BS transmit power to the MTs on the LR can be implemented with and without the SR cooperative approach, and their performance can be compared.

D. MT Processing Capabilities

An important issue of practical interest is whether the MTs receive the data over LTE first then communicate over Bluetooth, or whether they can communicate over the two wireless interfaces simultaneously. The optimal approach and the proposed fair method can be implemented in both scenarios without any modification in their formulations. However, in practice, communication over one interface at a time will increase the delay in receiving the content, whereas simultaneous communication raises the issue of the capabilities of MTs in terms of their ability to run the processing for two wireless interfaces in parallel and in real time. Furthermore, it would be interesting to determine the MT power consumption when two interfaces are simultaneously active compared to the scenario where one is active at a time.

VI. CONCLUSIONS

A low complexity energy-efficient content distribution approach with mobile-to-mobile cooperation was presented. The communication networks considered were LTE on the long range and Bluetooth on the short range. The proposed approach was compared to the optimal solution. It was shown to ensure more fairness at the expense of a slight performance degradation in terms of energy savings. However, significant energy savings were obtained compared to the non-cooperative scenario.

REFERENCES

[1] F. Fitzek and M. Katz, *Cooperation in Wireless Networks: Principles and Applications*. Springer, 2006.

[2] U. Lee, S. Jung, D.-K. Cho, A. Chang, J. Choi, and M. Gerla, “P2P Content Distribution to Mobile Bluetooth Users,” *IEEE Transactions on Vehicular Technology*, vol. 59, no. 1, pp. 356–367, January 2010.

[3] Q. Zhang, F. H. P. Fitzek, and V. B. Iversen, “Design and Performance Evaluation of Cooperative Retransmission Scheme for Reliable Multicast Services in Cellular Controlled P2P Networks,” *In Proceedings of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, September 2007.

[4] M. Ramadan, L. Zein, and Z. Dawy, “Implementation and Evaluation of Cooperative Video Streaming for Mobile Devices,” *In Proceedings of IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications*, September 2008.

[5] L. Al-Kanj and Z. Dawy, “Optimized Energy Efficient Content Distribution over Wireless Networks with Mobile-to-Mobile Cooperation,” *IEEE ICT 2010*, April 2010.

[6] H. Ekström, A. Furuskär, J. Karlsson, M. Meyer, S. Parkvall, J. Torsner, and M. Wahlqvist, “Technical Solutions for the 3G Long-Term Evolution,” *IEEE Communications Magazine*, vol. 44, no. 3, pp. 38–45, March 2006.

[7] Bluetooth SIG, “Specification of the Bluetooth System, Blutooth Core Specification version 4.0,” 2010.

[8] C.-H. Yang and S.-J. Lee, “Efficient Multicast Protocol for Supporting Mobile Nodes in Bluetooth Scatternets,” *Journal of Information Technology and Applications*, vol. 3, no. 1, pp. 1–11, 2008.

[9] C.-Y. Chang, K.-P. Shih, C.-H. Hsu, and H.-C. Chen, “A Location-Aware Multicasting Protocol for Bluetooth Location Networks,” *International Journal of Information Sciences (Elsevier)*, vol. 177, no. 15, pp. 3161–3177, August 2007.

[10] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.

[11] T. Lunttila, J. Lindholm, K. Pajukoski, E. Tiirola, and A. Toskala, “EUTRAN Uplink Performance,” *International Symposium on Wireless Pervasive Computing (ISWPC) 2007*, February 2007.

[12] 3rd Generation Partnership Project (3GPP), “3GPP TS 36.211 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation, version 8.3.0, Release 8,” 2008.

[13] 3rd Generation Partnership Project (3GPP), “3GPP TS 36.213 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical layer procedures, version 8.3.0, Release 8,” 2008.

[14] X. Qiu and K. Chawla, “On the Performance of Adaptive Modulation in Cellular Systems,” *IEEE Transactions on Communications*, vol. 47, no. 6, pp. 884–895, June 1999.

[15] R. Jain, *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation and Modeling*. New York: Wiley, 1991.

[16] M. Salem, A. Adinoyi, M. Rahman, H. Yanikomeroglu, D. Falconer, Y.-D. Kim, E. Kim, and Y.-C. Cheong, “An Overview of Radio Resource Management in Relay-Enhanced OFDMA-Based Networks,” *IEEE Communications Surveys and Tutorials*, vol. 12, no. 3, pp. 422–438, Third Quarter 2010.

[17] 3rd Generation Partnership Project (3GPP), “3GPP TR 25.814 3GPP TSG RAN Physical Layer Aspects For Evolved UTRA, v7.1.0,” 2006.

[18] W. Saad, Z. Han, M. Debbah, A. Hjørungnes, and T. Basar, “Coalitional Game Theory for Communication Networks: A Tutorial,” *IEEE Signal Processing Magazine, Special Issue on Game Theory*, vol. 26, no. 5, pp. 77–97, September 2009.