Enabling Technologies of Energy Efficient Cooperative M2M Networks: Benefits and Challenges

Najah AbuAli
College of IT, United Arab Emirates University,
Al-Ain, United Arab Emirates
najah@uaeu.ac.ae

***Abstract*—Cooperative Communication (CC) and Machine to Machine (M2M) networks have recently emerged as promising techniques for improving spectral efficiency and extending network coverage. CC generated significant interest in the research community for optimizing Energy Efficiency (EE) in next-generation networks. However, envisioning CC as an energy-saving solution for M2M networks gives rise to unresolved problems and significant challenges. In this paper, we discuss the enabling technologies for cooperation in M2M networks, the benefits and challenges of employing these technologies and the open research issues. We first provide an overview of each technology for cooperation in M2M networks. We then study the interaction between the cooperation techniques and the M2M energy-efficient networks employing each of these technologies. We also provide the latest standardization activities of M2M communication in LTE-Advanced networks.**

I. Introduction

Recent years have been hallmarked by significant growth and advances in wireless access networks including M2M systems, devices and applications, which escalated the usage demand and traffic of these networks. Development in the wireless access industry advanced the access network operators to the top list of energy consumers. The increase of energy consumption is expected to increase with the heightened demand of wireless access communication.

Significant research and effort have been allocated towards providing solutions to enhance networks' energy efficiency. The researchers' effort addressed EE at different levels of the access network: component level, link level, and system level. Researchers also considered shifting wireless technologies, network protocols and architectures to allow for more efficient use of energy.

Network architecture has been one of the major concerns in wireless access networks. However, the interest in network architecture and deployment focused on mitigating interference and increasing spectral efficiency and extending network coverage. Employing network architecture as a strategy for reducing energy consumption has attracted recent attention. Different techniques were proposed in literature for a more energy-efficient network deployment, mainly by optimizing the cell size, exploring cognitive radio and heterogeneous networks (overlaying macrocells with femto, pico, and microcells), and locating non-cooperative and cooperative relay nodes. Among all network architecture techniques, cooperative relaying attracted special attention. Cooperative relaying still imposes non-trivial challenges and unanswered questions regarding energy consumption concerns despite the significant amount of research that addressed different issues in that field, such as increasing network capacity and extending network coverage.

In this paper, we discuss different enabling technologies in M2M cooperative networks (mainly focussing on M2M communication in LTE-Advanced networks). We discuss the open research issues and current challenges to enabling energy-efficient cooperative networks. We proceed in Section II by presenting a brief review and latest standardization efforts of M2M LTE-Advanced networks. In Section III we overview the cooperative communication networks. Section IV discusses the enabling technologies for energy-efficient and cooperative M2M networks, challenges and open research issues. Finally, we conclude the paper in Section V.

II. Machine to Machine LTE-Advanced Networks

LTE-Advanced M2M communication (a.k.a Machine Type Communication (MTC)) will assume a considerable share in the projected traffic increase in future networks. This motivates 3GPP effort in enabling operator networks to satisfy the requirements of MTC applications, while providing satisfactory service to both human and machine applications. Already various issues have been addressed in Releases 10 and 11, including overload and congestion control, low priority access, downlink throttling, addressing space, device trigger, and defining interfaces between MTC servers and the mobile network.

Latest standardization efforts in Release 12 [1] of LTE-Advanced standards continue to be motivated by maintaining both human and machine type communication. Enhancements,

This work was made possible by NPRP grant NPRP4-553-2-210 from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors

978-1-4799-0540-9/13/$31.00 ©2013 IEEE

such as optimizations for co-located MTC devices, location tracking and network selections are being introduced. We consider three major enhancements that have either been introduced or that are currently under consideration, namely traffic categorization, dedicated cores, and Device to Device (D2D) communications.

A. Traffic Categorization

TS 22.368 [1] distinguishes specific modes of MTC, including small data transmissions, time-controlled and group-based communication. Different measures are undertaken to reduce communication requirements in terms of signalling overhead and network resources, and minimizing the delay for reallocation for small data transmissions. The devices can be either attached or detached from the network. The system must recognize communications instances for charging purposes.

Machines communicating in a time-controlled manner serve applications that can tolerate to send or receive data only during defined time intervals, and thus require reduced signalling. Time-controlled devices may communicate outside these intervals and be charged.

The standard does not specify how ”grouping” should be made for group communications, thus deferring the issue to operators and vendors. The standard specifies that features assigned to some machines within a group may not necessarily be assigned to others. This includes QoS policy features, where an operator can specify a Group-Based Policing MTC feature.

B. Architecture for Device to Device MTC

A prominent enhancement for MTC in Release 12 is the introduction of an architecture for D2D communication. There are several modes for D2D. Devices can communicate over the 3GPP networks or through an MTC server. Grouped devices can also communicate directly with other devices exclusively within the group. Only one device in grouped communication, the MTC gateway, connects to the 3GPP networks in its radio. Local connectivity within the group can be in IEEE 802.16, Zigbee, Bluetooth, etc.

C. Dedicated M2M Core

MTC may affect human type traffic at the network core as the number of machines utilizing 3GPP networks increases. Recent research has been undertaken to developed a dedicated network core to divert the MTC traffic. This marks an architectural feature that would become particularly advantageous in instances of congestion. The separation allows for further enhancements, including shared cores between several M2M service operators, or having multiple cores within the same network.

III. Cooperative Communication Relaying

The significant need for higher capacity in contemporary access networks has dictated an ongoing effort to improve network capacity. Cooperative Communication (CC) has offered itself as a promising technique to meet this need in the last decade. It makes use of the different available resources to cooperate in improving several performance measures of the network such as throughput, packet loss, and network lifetime. Cooperative communication techniques can be divided into two major categories based on the type of resource that is utilized in the collaboration; Cognitive radio and relaying. Cognitive radio is based on utilizing the frequency and time resources of the network. Network users who are employing cognitive radio techniques normally collaborate by temporarily sharing the frequency bands to improve the network frequency spectrum utilization.

The relaying technique was motivated by exploiting the spatial communication diversity of using multiple antennas for transmission and reception (MIMO). Some devices, such as handheld devices, cannot equip multiple antennas due to the device requirements and capabilities. Hence, utilizing neighboring nodes which are equipped with single antenna to produce a virtual MIMO system is motivated. CC networks make use of the wireless media broadcast transmission, where a transmission from a source to a destination is overheard by the relaying nodes. Hence, a source node transmits to a destination in one timeslot of the frame since the transmission for most access netowrks is scheduled on frame bases. The relay node, which overheard the transmission is collaborating in relaying the source transmission to the destination in the next timeslot. The destination node extracts a stronger signal from the two received signals exploiting the spatial diversity and consequently improving the network capacity. There are two types of relaying in CC systems; amplify and forward and decode and forward. In amplify and forward, the relay node receives the signal, amplifies it and forwards it without processing the signal or decoding it as opposed to decode and forward relaying type. Another benefit from utilizing CC relaying is improving the energy efficiency of transmission through decreasing the transmission power, for example.

A. Cooperative Communication in M2M Networks

Cooperative communications is a promising technique that can be employed to enhance several performance measures of the M2M network. For example, M2M devices can utilize cooperative communication to efficiently utilize network radio resources, extend network lifetime, alleviate interference, and extend network coverage. However, employing cooperative communication is still at its early stages of research with present open research problems, such as channel modeling of cooperative communication in M2M networks and how and when to employ cooperation for optimal network performance. Several researchers explored benefits, applicability and challenges for cooperation in M2M network. The work in [2] discusses the necessity of cooperation in low power M2M networks due to two main limitations; transmission range limitation and processing complexity limitation. Range limitation can be overcome through cooperation. Consequently, long distances towards gateways in M2M networks can be covered by means of multiple short hops. Complexity limitation can also be surmounted by cooperation, which allows counteracting the limited per-device complexity to achieve a more powerful system-wide complexity. Karnouskos [3] explores the heavy dependence of Smart Grid successful implementation on cooperation at various network layers (horizontally and vertically). Karnouskos focuses on the enabling aspects of cooperation between the Internet of Things and its interactions for smart house and Smart Grid implementation. The work in [4] shows how cooperation in M2M networks can extend the network life. The authors extended a cooperative MAC protocol [5] , Persistent Relay Carrier Sensing Multiple Access (PRCSMA), that operates in 802.11 networks DCF mode into M2M networks. PRCSMA, which implements a Cooperative Automatic Retransmission Request (C-ARQ) scheme at the MAC layer, is modified to coordinate the retransmission from devices of the M2M network. Andreev et al. [6] propose an energy-efficient cooperative relaying scheme for M2M networks to extend the network's lifetime. The work focuses on enhancing the performance of cell-edge M2M devices with a poor communication link and propose relay cooperation to improve the link performance.

IV. Enabling Technologies

In the following subsections we discuss several techniques employed in CC and M2M networks to increase the energy efficiency, mainly: Network Coding (NC), Radio Resource Management (RRM), Coordinated multi-Point Transmission (CoMP) and relay selection.

A. Network Coding

Network coding (NC) as opposed to source coding and channel coding is implemented at the intermediate nodes of the network rather than at the source and destination as seen in source and channel coding, respectively. A relay node participating in network coding receives several messages from different sources. An NC node uses arithmetic functions on the messages to produce a composite message then forward it to the destinations, consequently increasing the network capacity and decreasing the transmission power due to sending one message instead of multiple messages. Hence, the marriage between cooperative communication and network coding is intuitive, since NC is similar to CC in cooperating in relaying messages to destinations. However, The CC node is different from the NC in the fact that an NC node arithmetically manipulates messages before sending them for improved network capacity and efficiency. NC is of two types; traditional network coding, also known as digital network coding (DNC), and physical layer network coding, also known as analog network coding (ANC). In DNC, the message arithmetic manipulation is performed at the data link layer or upper layers. The ANC is performed at the physical layer, and the coding operation is performed naturally at the layer by allowing more than one source to simultaneously transmit their signals to the NC node at the same time. The ANC node in turn sends the signal results from the mixing process. We briefly demonstrate the differences between DNC, ANC and traditional CC relaying using the two-way relay model in a time-slotted frame system.

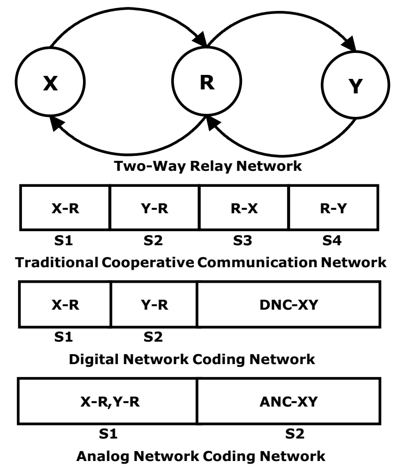

Fig. 1. Time-slot overhead in Traditional CC networks, DNC networks and ANC networks

Figure 1 shows a two-way relay network that consists of three nodes; X, Y, and R. In the traditional CC network, the source node X sends its message, X_R, to R in the first time slot, Y sends its message,Y_R, in the second time slot, R forwards the message, R_X to Y in the third time slot and forwards Y message, R_Y, to X in the fourth time slot. While in DNC, X sends its message to R in the first time slot, Y sends its message to R in the second time slot, and R manipulates the two messages arithmetically using the XOR operation, for example, to produce one message, DNC_{XY} that is broadcast to X and Y in the third slot. Node X uses an invertible function of the arithmetic operation performed at the DNC node on the received message DNC_{XY} and its own message to Y to extract the message sent by node Y to node X. Similar operation is performed at node Y to extract the message sent by X to Y. In ANC, node X and node Y send simultaneous messages X_R and Y_R, respectively to node R in the first time slot, node R broadcast the mixed signal, ANC_{XY} at the physical layer to node X and node Y in slot two. Hence, ANC reduces the time-slot overhead by one compared to DNC nodes and by two when compared to traditional CC node. This reduction is expected to improve the network capacity and energy efficiency since the number of transmission is reduced. However, since processing at the NC nodes is required, the energy efficiency is not always guaranteed. In the following subsection we discuss the energy efficiency in network coded cooperative and M2M networks.

1) Energy Efficiency in Network Coded Cooperative and M2M networks: Several researchers have explored the impact of network-coding on energy efficiency in cooperative communication relay networks. The work in [7] proposed a cooperative Automatic Repeat request MAC protocol algorithm to coordinate the transmission among a set of relay nodes in an IEEE 802.11 cooperative network. The authors exploit the network coding techniques to achieve an increase in the energy efficiency at the nodes helping in relaying. The authors evaluated their proposed algorithm against energy efficiency metric and demonstrated that the nodes running their algorithm have managed to increase the energy efficiency even with the increased processing mandated by the network encoding. The authors of [8] propose a scheme to select the best relay in a two-way relay network that minimizes total transmit power. They proved that their proposed scheme is optimal for minimal energy consumption and the optimal number of relay nodes to be selected in this setup is one. Zhi at. el. [9] designed a scheduler to allocate channel resources in a CC-DNC two-way relay network to increase energy efficiency. The authors compared the performance of their scheduler with and without the assistance of DNC. The authors claim that the assisted DNC scheduler was capable of increasing the energy efficiency by 50%. The authors of [10] utilize ANC to design an energy-aware routing protocol for CC networks. The authors compare their proposed protocol against the traditional shortest path routing algorithm and demonstrate that utilizing the ANC facilitates saving energy up to 37.5% in line topology network and 62.5% in grid topology network.

The work in [11] presents a digital network coding group communication scheme for M2M networks. The scheme collects data from the M2M devices and encodes it with random network coding in order to reduce the overhead control traffic in M2M networks. However, this work focuses on the data transmission efficiency rather than energy efficiency. Similarly, the network coding scheme proposed in [12] focuses on improving the data transmission efficiency rather than energy by reducing the interference between the cellular user and the M2M device.

The aforementioned schemes anticipate the significant performance gain in energy efficiency of unifying CC and M2M communication with NC. However, most of the proposed schemes in literature are pure theoretical or primary experimental and mostly based on simplified assumptions that render implementation of these schemes impractical or restricted. We discuss some of the challenges and issues for real-world implementation of network coding in the following:

- Synchronization: most schemes in literature assume that the signals superposition at the physical layer is synchronized. CC-ANC mandates accurate symbol timing and carrier phase information at all nodes participating in the CC-ANC schemes. Hence, the requirements for tight synchronization of time, frequency and phase for proper practical operation of CC-ANC. Additionally, CC-ANC requires same modulation type of the mixed signals and flat fading channels. Recently, some researchers attempt to address Asynchronous ANC operation. However, this is still a hot area of research.
- NC noise: The authors of [13] debate that both types of NC may not be always beneficial for CC due to ”NC noise”. A node can be a source and destination at the same time in two-way relay communication. Hence, a node can send a signal to another node and receive another signal as well. When a network-coded signal (a mix of all sources signals) is received from the relay at one of the sources, the source attempts to extract the signal sent to it by other sources by subtracting the signal it sent to another source from the network coded signal and subsequently extract the signal meant to be sent to it by other sources. The signal used at the source is different from the signal component in the network-coded signal. This difference is identified by authors as NC noise. This noise may be large enough to render the relay path unusable and worse than the direct path of transmission.
- Complexity: Unifying CC and NC increases the system complexity. The trade off between the energy efficiency performance gain among other performance gains and the complexity was partially investigated. This problem is still an open area of research.
- Relay Type: Decode and forward relaying and ANC entails high cost, while amplify-and-forward and ANC amplifies noise as well. On the other hand decode and forward and DNC is less costly and suppresses noise much better the amplify and forward. Rigorous comparison between DNC and ANC is partly investigated and there are some uncertainties still in this area. Irrespective from the fact that the research community agrees on retaining the use of DNC, a quantitative study of a performance gain between the two types is still needed.
- Network coding in M2M networks techniques entails additional difficulties due to
  - The M2M devices are constraint in processing power and energy, network coding may consume the device resources in retrieving the received signal.
  - Due to mobility, M2M devices may join and leave networks at a rate higher than conventional users, hence, the topology is in continuous change. consequently, the network coding technique may not be as efficient tool as it is compared to conventional networks.
  - The small data traffic generated by M2M devices, which may be few bits for some applications renders the network coding technique unusable in these M2M networks.

B. Radio Resource Allocation

Most of wireless access networks including M2M systems employ OFDMA as the multiple access technology, because OFDMA supports high spectral efficiency and is easily implemented. OFDMA networks utilize frame access structure, where the frame is divided into time slots in time dimension and a set of orthogonal subcarriers in the frequency direction. Multiple access is achieved in OFDMA wireless networks by allocating the same time-slots and different subcarriers to different users or vice versa. Improvement of spectral efficiency in OFDMA over other technologies is achieved by allocating subcarriers adaptively based on the channel quality of the user links (SNR); i.e. subcarriers are allocated to users with high SNR. This strategy, along with enhancing the spectral efficiency of the network, also decreases the transmission power of the allocated subcarriers, and consequently reduces the energy consumption. OFDMA resource allocation in relay networks is more challenging and demands careful design over single hop networks. Schemes that meet a global objective (for example minimizing energy consumption or maximizing system capacity) are not trivial to design, since maximizing the network capacity may result in increasing the total energy consumption in the network. On the other hand, minimizing the energy consumption alone impedes the network total capacity performance. Therefore, it is important to find a balance between energy efficiency and other network performance measures, such as network capacity and users' fairness.

Introducing M2M communication into current and future networks adds more complexity to the resource allocation problem due to the fact that M2M networks are expected to coexist with Human to Human (H2H) networks. The co-locating M2M communication within the H2H systems should not degrade performance of existing H2H systems. Radio resource allocation is addressed employing two major strategies; orthogonal resource allocation and reuse resource allocation. Orthogonal allocation eliminates interference but also leads to low-system capacity and throughput. Meanwhile, reusing the resources assigned to H2H networks at the M2M network can achieve a higher spectral efficiency; it increases the level of interference compared to the orthogonal strategy. The cooperative game scheme proposed in [14] studied the best mode selection of orthogonal or reuse resource modes and cooperative transmission for D2D communications. The scheme defines a transmission cost for each device in the system in terms of transmission power and the price of channel occupancy. A device decides to cooperate in communication with other users in a group or coalition if it can achieve a lower transmission cost. Hence, the device decides the mode of transmission; orthogonal or reuse mode. The work in [14] optimally decides the best transmission mode although there is no consideration for energy consumption.

To the author's knowledge, there is not any work in literature that explored energy-efficient resource allocation in cooperative M2M networks. However, the concept of power allocation to extend non-cooperative M2M network lifetime has been addressed as seen in [15], which proposes a power allocation algorithm for M2M network with off-grid multiple energy sources. The authors of the article solve an optimization problem constraint by the device circuit energy consumption, the finite battery storage capacity, and the system data rate requirement to maximize the energy efficiency of the M2M network. Similarly, resource allocation scheme is proposed in [16], which also performs M2M device grouping to minimize total energy consumption of the non-cooperative M2M system in both flat-fading and frequency selective fading channel.

Other research addresses energy-efficient resource allocation in conventional cooperative networks. However, most of the current literature of resource allocation schemes for CC networks address the problem of improving the network capacity, coverage enhancements and efficient relay selection. Few schemes are proposed in literature with the objective of improving the energy efficiency in CC networks. For example in [17], authors propose a scheme to choose between the direct communication link or the relay path based on which one requires less transmission power. The work in [17] focuses on optimizing the transmission power only. Another work attempted to meet the end-to-end SNR user's requirement while optimizing the transmission power as presented in [18]. However, fairness among users is overlooked since users and relay nodes are selected randomly. The work in [19], attempted to optimize the user selection while optimizing the transmission power. It overlooks the energy cost of signalling among the nodes, although it attempt to striking a balance between capacity and energy optimization. The authors of [20] design a scheme to adaptively assign subcarriers with fair power control strategy that minimize a cost function of average relay powers. The scheme attempts to balance the trade-off between energy efficiency and fairness by joint optimal subcarrier and power-allocation. However, the scheme's cost function overlooks the system capacity.

We observed that most of the work addressing energy efficient resource allocation in conventional cooperative relay networks focuses on optimizing either energy consumption or system capacity only. The few proposals which attempt to strike a balance between energy consumption and system capacity optimization overlooked the QoS requirements or did not account for signalling cost in CC network. Additionally, most proposals assumed a global channel state information, which is often difficult to obtain in practice. Hence, investigations of the effect of imperfect CSI information on energy efficient scheduling is an open area of research. Signaling overhead, relaying strategy (amplify-and -forward or decode-and-forward), centralized or distributed requires further investigation, since these areas of research still entail uncertainties. As a final note, scheduling schemes proposed for CC networks assumes simplified networks like the 3 nodes relay network or two-way relay networks, designs for practical random technology networks including M2M systems is needed.

C. CoMP

In their use of OFDM-based multi-carrier access techniques, Wireless access networks are inherently interference-limited networks. The main objective of utilizing CoMP in these networks is to enhance the users throughput performance at the cell edges. This mitigation is achieved by coordinating transmissions and receptions over multiple cells, i.e., the cell serving the user and its neighboring cells. CoMP as opposed to cooperative relay is considered as a node cooperative system.

Node cooperation can be achieved by two procedures; Joint processing among communicating users or by coordinating communication among users through scheduling. In joint processing, users data is Transmitted(Received) jointly at multiple points (part of or entire CoMP cooperating set) at a time, e.g., to improve the received signal quality. Coordinated Scheduling and Beamforming (CS/CB) user scheduling and precoding selection decisions are made with coordination among points corresponding to the CoMP cooperating set. Integrating CoMP technology to the cooperative relay is possible in a CoMP system that includes relay nodes within a cell. Since the data is available in this case at both the base station and the relay node cooperation can be achieved by for example doing joint processing at both nodes. Integration between CoMP and relay technology was proposed for consideration in LTE standard in release-11 and still under consideration in release-12 and beyond.

At the cell edge, the user normally communicates with the base station in a single cell system with higher power transmission. On the other hand, the impact of CoMP on energy efficiency is still to be investigated. The authors of [21] compared the improvement of energy efficiency of the CC relay against CoMP. They investigated the energy efficiency of a single BS, CoMP system and wireless relaying system by turning off certain BSs while meeting average outage constraint. The authors evaluated the energy efficiency performance when changing two system parameters; traffic intensity and network density. They concluded that nodes in the relay system need to be designed with as low energy cost as possible to get high energy efficiency performance, otherwise CoMP system outperforms the relay system.

The authors of [22] investigated the trade-offs between spectral efficiency and energy efficiency for uplink CoMP and non-cooperative systems. They observed that under idealistic power consumption model, energy efficiency can be achieved by two factors power reduction and spectral efficiency improvement when using CoMP, and CoMP has better energy efficiency than non-cooperative networks. However, for a realistic power consumption model, improvement in energy efficiency in uplink CoMP over non-cooperative systems can only be achieved via spectral improvement. CoMP is more energy efficient than non-cooperative system for cell edge communication. The latter finding was also proved by the investigations presented in [23]. Up to the author's knowledge, there are not any current literature that investigate the energy efficiency performance as a result of combining CoMP with CC in conventional or M2M networks. However, Han and Ansary suggested exploiting cooperation in CoMP between a primary cell and a secondary cell by allowing the secondary cell in a CoMP system to cooperatively relays the signal from the primary BS to the primary user. The primary user receives two signals; the signal directly transmitted from the primary BS and the signal relayed by the secondary BS.

This area of research still needs considerable investigation and the deployment of CoMP for performance improvement of energy efficiency is still unlocked in conventional and M2M networks.

D. Relay Selection

There are several relaying nodes available between the source and destination that can relay the source message to the destination to achieve cooperative diversity gain in a dense wireless access network. All candidate relay nodes can participate in forwarding a message toward the destination for better reliability. However, the spectral efficiency of the network is severely degraded relative to the number of nodes participating in the cooperative communication. Assuming a time-slotted system with N relay nodes, (N - 1) time slots is needed for the message transmission if all relay nodes participated in relaying the message. Hence, delay is increased over non-cooperative transmission alongside the present consumption of the network's scarce resources, such as spectrum and energy, since the destination will wait to receive all transmissions from all relay nodes. It is shown in [24] that a single optimal relay can be selected from the set of candidate relays to participate in transmission to achieve similar cooperative diversity of multi-relays but improved spectral efficiency and reduced delay.

Optimally selecting single relay in conventional cooperative networks has been extensively researched to improve the network performance parameters such as network capacity, outage probability and energy efficiency. The work in [25] provides an extensive survey of relay selection with different optimization objectives. The problem of relay selection in M2M networks differs from conventional cooperative networks in several aspects; the interference between M2M devices and H2H devices should be taken into consideration in selecting the best relay, the relay should be selected to ensure reliable communication of both H2H communication and M2M communication not only M2M or H2H networks. Thus, all links including channels between the base station and the user equipment, the base station and the M2M device and the M2M devices should be considered. The topology of M2M communications is dynamic due to the addition and removal of M2M links, which may complicate the relay selection problem in M2M networks.

The authors of [14] proposed a distributed relay selection scheme for D2D networks when the D2D and the User Equipment (UE) share the uplink cellular radio resources. The scheme considers the interference from the D2D system to base station and from user equipment to D2D system, and elects the candidate relay accordingly taking into account the status of the channel and transmit power of both the source to relay and relay to destination links. The best relay is then selected randomly among the candidate relays. The reference [26] proposes three relay selection strategies in M2M networks; SNR-based selection strategy, distance-based selection strategy, and SNR and remaining energy selection strategy. The authors proved via simulation that the later strategy can extend the lifetime of the M2M network at the expense of the transmission power, which is useful in energy-constrained terminals.

Relay selection is exhaustively researched in conventional cooperative communication networks, but there are still some open issues, which are inherited into the M2M cooperative communication networks besides the specific M2M difficulties related to relay selection, which we discuss in the previous paragraph. For example, most proposals addressed the problem in conventional cooperative networks focus on the best relay selection in a single source-single destination setup. Few proposals addressed optimal relay selection for improved energy efficiency in multi-source multi-destination single relay selection, multihop communication relay selection, and multiple radio access technologies (heterogeneous networks). Additionally, most proposals assumed correct channel state information, which may not be practical. Hence, designs for optimal relay selection with imperfect channel state information stands as an open issue in research. Another issue is the optimal selection of best relay with fairness consideration and incentive mechanism, especially in heterogeneous network or energy constraint networks such as M2M networks, which may involve relay nodes that are not managed by the same network operator.

V. Conclusions

We present in this paper the several enabling technologies for energy efficiency in cooperative and M2M networks, mainly, network coding, resource allocation, CoMP and relay selection. We discuss the benefits, challenges and open research issues for each technology. We observe that irrespective of the several benefits that the cooperative communication can bring to the M2M networks, little to no research has employed these enabling technologies together with cooperative communication in M2M networks. We note that not all enabling technologies discussed in this paper can assist in reducing energy consumption, on the contrary some may entail additional energy cost,for example network coding, especially for power constraint M2M devices.

References

[1] T. . v12.0.0, "Study on enhancements for machine-type communications (mtc)," tech. rep., 3GPP, March 21, 2013.

[2] A. Bartoli, M. Dohler, J. Hernández-Serrano, A. Kountouris, and D. Barthel, "Low-power low-rate goes long-range: the case for secure and cooperative machine-to-machine communications," in *NETWORKING 2011 Workshops*, pp. 219–230, Springer, 2011.

[3] S. Karnouskos, "The cooperative internet of things enabled smart grid," in *Proceedings of the 14th IEEE international symposium on consumer electronics, Braunschweig, Germany*, pp. 07–10, 2010.

[4] G. Botter, J. Alonso-Zárate, L. Alonso, F. Granelli, and C. Verikoukis, "Extending the lifetime of m2m wireless networks through cooperation," in *Communications (ICC), 2012 IEEE International Conference on*, pp. 6003–6007, IEEE, 2012.

[5] J. Alonso-Zárate, E. Stavrou, A. Stamou, P. Angelidis, L. Alonso, and C. Verikoukis, "Energy-efficiency evaluation of a medium access control protocol for cooperative arq," in *Communications (ICC), 2011 IEEE International Conference on*, pp. 1–5, IEEE, 2011.

[6] S. Andreev, O. Galinina, and Y. Koucheryavy, "Energy-efficient client relay scheme for machine-to-machine communication," in *Global Telecommunications Conference (GLOBECOM 2011), 2011 IEEE*, pp. 1–5, IEEE, 2011.

[7] A. Antonopoulos, C. Verikoukis, C. Skianis, and O. B. Akan, "Energy efficient network coding-based mac for cooperative arq wireless networks," *Ad Hoc Networks*, 2012.

[8] M. Zhou, Q. Cui, R. Jantti, and X. Tao, "Energy-efficient relay selection and power allocation for two-way relay channel with analog network coding," *Communications Letters, IEEE*, vol. 16, no. 6, pp. 816–819, 2012.

[9] Z. Chen, T. J. Lim, and M. Motani, "Energy minimization in two-way relay networks with digital network coding," in *IEEE Intl Conf. Comms. in China (ICCC), Beijing, China*, 2012.

[10] M. N. A. Akhtar and A. Aghvami, "On the use of cooperative physical layer network coding for energy efficient routing," *IEEE Transactions on Communications*, vol. PP, no. 99, pp. 1–12, 2013.

[11] R. Y. Kim, "Network coded group communication scheme in machine-to-machine communications," in *ICT Convergence (ICTC), 2011 International Conference on*, pp. 780–781, IEEE, 2011.

[12] Z. Zhao, S. Shao, and J. Sun, "The research of network coding in d2d communication system," 2013.

[13] S. Sharma, Y. Shi, J. Liu, Y. Hou, S. Kompella, and S. F. Midkiff, "Network coding in cooperative communications: friend or foe?," *IEEE Transactions on Mobile Computing*, vol. 11, no. 7, pp. 1073–1085, 2012.

[14] X. Ma, R. Yin, G. Yu, and Z. Zhang, "A distributed relay selection method for relay assisted device-to-device communication system," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on*, pp. 1020–1024, IEEE, 2012.

[15] D. W. K. Ng and R. Schober, "Energy-efficient power allocation for m2m communications with energy harvesting transmitter," in *Globecom Workshops (GC Wkshps), 2012 IEEE*, pp. 1644–1649, IEEE, 2012.

[16] C. Y. Ho and C.-Y. Huang, "Energy-saving massive access control and resource allocation schemes for m2m communications in ofdma cellular networks," *Wireless Communications Letters, IEEE*, vol. 1, no. 3, pp. 209–212, 2012.

[17] I. Krikidis, J. S. Thompson, and P. M. Grant, "Cooperative relaying with feedback for lifetime maximization," in *Communications Workshops (ICC), 2010 IEEE International Conference on*, pp. 1–6, IEEE, 2010.

[18] V.-A. Le, R.-A. Pitaval, S. Blostein, T. Riihonen, and R. Wichman, "Green cooperative communication using threshold-based relay selection protocols," in *Green Circuits and Systems (ICGCS), 2010 International Conference on*, pp. 521–526, IEEE, 2010.

[19] R. Devarajan, S. C. Jha, U. Phuyal, and V. K. Bhargava, "Energy-aware resource allocation for cooperative cellular network using multi-objective optimization approach," *Wireless Communications, IEEE Transactions on*, vol. 11, no. 5, pp. 1797–1807, 2012.

[20] D. Wang, Z. Li, and X. Wang, "Joint optimal subcarrier and power allocation for wireless cooperative networks over ofdm fading channels," *Vehicular Technology, IEEE Transactions on*, vol. 61, no. 1, pp. 249–257, 2012.

[21] D. Cao, S. Zhou, C. Zhang, and Z. Niu, "Energy saving performance comparison of coordinated multi-point transmission and wireless relaying," in *2010 IEEE Global Telecommunications Conference (GLOBECOM 2010)*, pp. 1–5, IEEE, 2010.

[22] O. Onireti, F. Heliot, and M. Imran, "On the energy efficiency-spectral efficiency trade-off in the uplink of comp system," *IEEE Transactions on Wireless Communications*, vol. 11, no. 2, pp. 556–561, 2012.

[23] F. Héliot, M. A. Imran, and R. Tafazolli, "Energy efficiency analysis of idealized coordinated multi-point communication system," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, pp. 1–5, IEEE, 2011.

[24] A. Ibrahim, A. Sadek, W. Su, and K. J. R. Liu, "Cooperative communications with relay-selection: when to cooperate and whom to cooperate with?," *Wireless Communications, IEEE Transactions on*, vol. 7, no. 7, pp. 2814–2827, 2008.

[25] S. Abdulhadi, M. Jaseemuddin, and A. Anpalagan, "A survey of distributed relay selection schemes in cooperative wireless ad hoc networks," *Wireless Personal Communications*, vol. 63, no. 4, pp. 917–935, 2012.

[26] W. Xia, S. Shao, and J. Sun, "Multi-relay selection strategy for device to device communication," 2013.