Multi-Hop Communications inside Cellular Networks: A Survey and Analysis

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***Abstract*—The access part of all cellular networks generation suffers from common issues related to dead spots (parts that are not covered by the network) and hot spots (parts where the number of users is huge compared to network resources). During the last eighteen years, lots of research proposals have tried to overcome cellular problems through MCN (multi-hop cellular networks) architectures which is a new paradigm allowing the extension of cellular access part via ad-hoc networks. In this paper, we propose a survey of different MCN architectures. We identify the key MCN classification factors, we compare the proposed architectures with advantages and drawbacks of each one, and then we discuss some open issues related to this subject.**

***Index Terms*—Ad-hoc, cellular, mobile, multi-hop**

I. Introduction

Cellular networks have known a huge evolution in the last eighteen years. From 2nd generation to 3rd and 4th generations then 5G in the few coming years, cellular networks constitute a mandatory communication technology nowadays. However, as all radio communications, the access part in all cellular networks suffers from multitude of issues that may impact the end user services. In fact, dead spots constitute a major drawback in such networks. In this kind of areas, received signal is very weak due to wave propagation obstacles like shadowing, interferences and multi-paths…). Cellular clients in such areas (lift, tunnel, edge of network…) cannot benefit from telecommunication services. Another drawback in cellular networks is hot spots. In such areas, the number of cellular clients is very huge in comparison to network resources. This phenomenon may impact client services especially data services that require big end to end throughput.

To face this kind of issues, telecommunication operators have to deploy more infrastructures and ensure enough network resources that may provide good services to the end client. In fact, micro-cells and pico-cells can be deployed in areas suffering from weak signals and lack of cellular resources. However, the cost related to this purpose is very huge since it includes planning cost, energy cost, maintenance cost, frequency licenses cost, etc.

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Multi-hop cellular networks (MCNs) may constitute an important alternative to overcome major cellular network drawbacks especially in access part. In fact, a mobile in bad coverage conditions may relay its data through one or more other mobiles to reach the base station. Hot spots can also relay their load to neighbor cells less congested through relaying devices. MCNs provide then potential solutions to extend cell coverage, enhance cell capacity and overcome dead spot and hot spot drawbacks with less infrastructure deployment and cost.

The rest of this paper is organized as follows. In section II we will present the general MCN concept and architecture and will discuss MCN classification factors. Section III will be dedicated to describe and compare main proposed MCN architectures during last eighteen years. In section IV, we will address some research challenges related to MCN purpose. Section V concludes the paper.

II. MCN Architecture & Classification Factors

MCN communication consists on the communication between a BS (base station) and a MT (mobile terminal) through one or more relays in order to enhance cellular performances especially those related to data end to end throughput [1]-[4]. This communication can be performed either in licensed frequency bands, in free frequency bands ISM (industrial, scientific and medical) or in hybrid bands. Relays in MCN architecture can be either mobile or fixed relays. The classification factors of MCN architectures will be detailed bellow.

As shown in Fig. 1, the MT out of cellular coverage can use a set of MTs to transmit data to BS. MCN architecture can be shown as combination between cellular communication and MANET (Mobile Ad hoc Network) communication. The main purpose of MCN architecture is to enhance the access part of cellular network [5]. It allows mobiles in dead spot and/or hot spot areas to benefit from telecommunication services as in normal conditions [6], [7].

The general MCN architecture consists then in allowing MT to transmit its data to a BS through one or more relays. Nevertheless, there are specificities that make differences between proposed MCN architectures in the last eighteen years, we can cite especially used frequency bands for transmission, number of used interfaces in MCN communication, using of charging and

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rewarding mechanisms, relay nature and routing strategy inside ad-hoc part [8]. In the following, we will present the main MCN architectures classification factors.

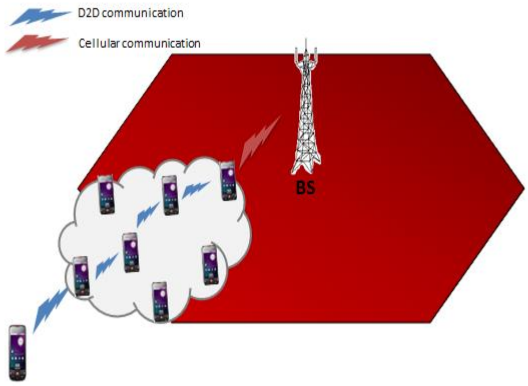

Fig. 1. MCN architecture.

Frequency bands: frequency bands are the main design factor in MCN classification. In fact, there are 3 possible ways to communicate in MCN architecture. The first one is to use licensed frequencies in both relaying area and last hop link (link between the last MT and BS) [2], [9], [10]. In this case, channel assignment methods should take relaying part into consideration [11]-[14]. It is possible also to assign different frequency bands in relaying part and cellular part. The main issue with this possibility is the huge cost to own frequency licenses. The second way is to use free bands (ISM bands) in both cellular and relay parts. In this case, the BS can be considered as AP (access point) in WLAN (wireless local area network) [15]. The major issue with this architecture is the small range of the cell allowed by this kind of frequencies [16]. The third way is to combine licensed and free frequencies [17], [18]. In fact, the licensed bands can be used in cellular part and ISM bands in ad-hoc part. The major challenge with this architecture is to design a suitable routing protocol.

Number of used interfaces: MT nowadays can make simultaneous communications using different radio interfaces (cellular, WLAN, Bluetooth…). In MCN architecture, we may find communication using single interface (cellular/WLAN) or two interfaces.

Charging and rewarding mechanism: This factor is considered one of the most challenging factors in MCN architecture. It allows designing of a charging way to debit the client initiating the MCN communication. It also allows proposing rewarding mechanism for relaying MTs that contribute in MCN architecture [19].

Relay nature: MCN architecture may use either mobile [20], [21] or fixed relays [22], [23]. Mobile relays present complexities to manage mobility inside the architecture. Fixed ones require huge cost for deployment and maintenance.

Routing strategy: As already mentioned, routing is one of the main design factor in MCN architecture especially when ISM bands are used. We can talk about distributed routing [24] in which MTs try to find the best routing path for MCN architecture or centralized routing [25], [18] in which the BS or/and another fixed entity handle the routes between MTs.

III. Description and Comparison of Main Proposed MCN Architectures

In this section, we will describe, compare and discuss the main MCN architectures proposed during the last eighteen years. The comparison will be performed following the main classification factors discussed in the previous section.

A. Main Proposed Architectures

1) MCN[26]

This study was among the first ones proposing MCN architecture in its largest context. It compares the end-to-end throughput in the single cellular network (SCN) and MCN architecture. The SCN architecture concerns direct communication between a mobile and the base station.

The authors in this work suggested as example of study the access method RTS/CTS (request to send/clear to send) of IEEE 802.11 for the 2 parts of the MCN network (mobile to mobile and mobile to base station). The mainly setting used in this study is the factor $1/k$ illustrating the coverage of the MCN network compared to SCN. This parameter determines how much we can reduce the coverage of a MCN cell compared to a SCN cell (e.g. assume a SCN cell range 100 m; if k = 4 the coverage of the MCN cell is fixed to 25 m). As shown in Fig. 2, the number of BS in MCN architecture is lower than SCN architecture. This number is defined according the factor k.

The results of the study show that the end-to-end throughput in MCN networks is better than that of SCN networks. This rate is even better every time we decrease the coverage of MCN cells (increasing the value of the factor k).

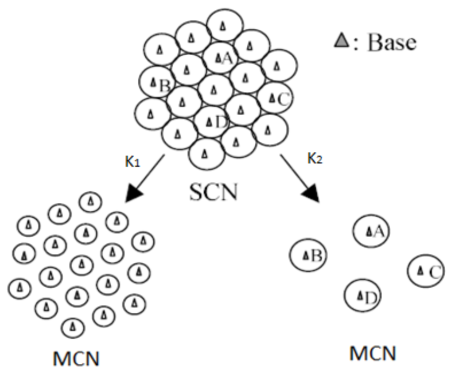

Fig. 2. MCN benefit comparing to SCN [26].

Discussion: As already stated, this proposal dealt with the MCN in a very large context, the authors were able to show the gain that MCN architecture can bring in particular regarding the end-to-end throughput. Nevertheless, the proposal ignores some important factors in the study, especially the mobility of relays. The proposal also assumes a very simplified MCN architecture using the same communication protocol in the two parts of the architecture (mobile to mobile and mobile to base station), which reduces its scope.

2) iCAR [22]

The authors proposed a new architecture for cellular networks to bypass congestion issues. The authors introduced the concept of ARS (Ad hoc relay stations) nodes that are placed in specific locations of the cells to ensure the relay of mobile traffic.

The proposed architecture allows both to find an alternative to a mobile on a congested cell (CI: congestion induced) and guarantee a kind of load sharing between different cells (NCI: no congestion induced) in a group of n-cells. As shown in Fig. 3, if a MS X does not find a cellular frequency channel in cell B to initiate a communication link with BS B, it will send the traffic to its nearest ARS (ARS 1 in the figure), using frequency bands other than the cellular band. The ARS 1 will relay the traffic to another ARS (ARS 2 in the figure) in the neighboring cell (cell A in the figure). Finally, ARS 2 will forward the traffic to BS A using the cellular frequency channel.

Through simulation results, the proposal shows that the call rejection probability decreases in iCAR networks when the number of ARS in the cell increases. A high number of ARS can also ensure the establishment of a large number of simultaneous calls.

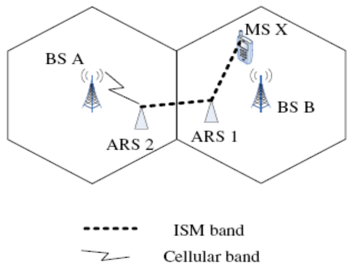

Fig. 3. Communication via ARS in iCAR architecture [22].

Discussion: The authors proposed an interesting architecture to overcome the congestion problem on 2G cells. Unlike MCN [26] proposal, relaying process is done using two different interfaces: R (ISM band) interface to communicate with the ARS and C interface (cellular band) to communicate directly with the BS if needed. The architecture is also based on fixed stations (ARS) controlled by the MSC (Mobile Switch Center), allowing better management of routing and a high degree of security of data exchanged between the mobile and the ARS. However, the architecture has some shortcomings, especially regarding the manner of establishing routes between concerned mobile and the various ARS and selection of the most optimal route. In addition, the introduction of ARS, as fixed nodes requiring a power supply, air-conditioning and maintenance tracking may present additional expense for the telecommunication operators.

3) AGSM [27]

Aggelou and Tafazolli proposed an architecture that combines GSM network and MANET (mobile Ad hoc network) in order to improve the quality of GSM service, especially the coverage in network dead spots (indoor, cell border ...).

The authors proposed an A-GSM interface as new interface that ensures communication in MANET network. A-GSM is based on the same protocol stack of the GSM air interface with certain modifications to the media access control (MAC) layer. The proposal defines cases where a mobile would have to initiate a handover to another mode of communication. This process includes three stages: The first one is to obtain information about signal strength received from the BS and neighbor mobiles, the second stage is to initiate the handover according to the available measurements in the mobile using a specific algorithm, the third phase is to control the handover. As shown in Fig. 4, mobiles in dead spots and indoor areas can establish communication to BS trough mobiles in line of sight (LOS) with BS using A-GSM interface.

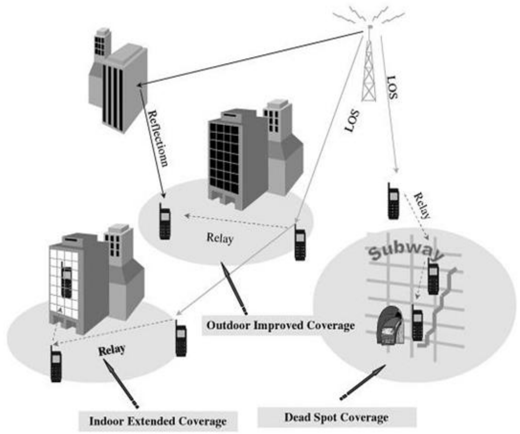

Fig. 4. Communication scenario using AGSM [27].

Simulation results show that the call success rate in A-GSM architecture can be improved up to 17% compared to GSM with equal number of nodes and equal number of dead spots.

Discussion: The proposal presented architecture to decrease dropped calls in dead spots of GSM network. The process of the proposed handover allows GSM customers to maintain a satisfactory quality of service. However, the proposal limits the architecture on GSM only (voice processing services), unlike MCN and iCAR which propose generic architectures that can handle voice and data services. Also, the paper does not provide routing algorithm in ad hoc network. In fact, the architecture is limited to the exchange of signaling messages between mobile and its one hop neighbors only. Finally, the study neglects to mention security, taxation and power consumption aspects that are critical factors in MANET networks.

4) CRS [28]

Unlike the previous proposals, the authors of this proposal focused their study on an important issue in MCN networks: What would oblige a MT to relay data of another MT knowing that this operation will affect its autonomy in energy and its CPU?

The paper answers this question by proposing a charging and rewarding mechanism in MCN architecture. Indeed, the client initiator of data packet will be debited and the relay client will be rewarded. The paper assumes, as shown in Fig. 5, the case of an exchange between a client A attached to a base station BSA and a client B attached to a base station BSB through the operator backbone.

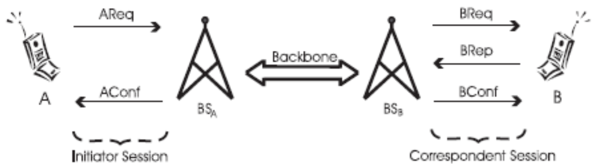

Fig. 5. Session establishment in CRS [28].

The proposed protocol can deal with any routing protocol, and overcomes several fraud cases. It uses two cryptographic blocks: Message authentication code (MAC) and stream cipher.

Discussion: This proposal is among the few ones treating the billing and rewarding issues in MCN architecture. Indeed, billing in this kind of architecture looks very delicate because the communication process is very complex. The paper proposed a protocol that can deal with the various cases of fraud that may arise. However, the authors did not specify the communication interfaces in different parts of the architecture (mobile-to-mobile and mobile-to-BS) and how to integrate the proposed protocol in these interfaces.

5) UCAN [29]

In the same perspective as the previous proposals, authors in [29] proposed an architecture that unifies cellular and ad hoc networks in order to increase downlink throughput. The architecture uses two different interfaces: radio interface of 3G network and 802.11 protocol between mobile relays.

Fig. 6. UCAN architecture [29].

As shown in Fig. 6, data is transmitted to destination client through proxy client, which has the best downlink rate and communicates directly with the base station, then via a relay client using IEEE 802.11 interface.

The authors proposed two types of protocols to identify the proxy client "greedy proxy discovery" and "on-demand proxy discovery". The first one consists in exchanging the average downlink throughput between mobiles in the same cell so that each mobile has information on the throughput of their neighbors. Then, a MT sends a RTREQ (request route message) to its neighbor which has the maximum throughput. This message is then forwarded to one of the neighbors having the better throughput, otherwise the MT initiates a proxy request to the base station which updates the proxy table. The second protocol "on-demand proxy discovery" consists of broadcasting RTREQ messages to build the proxy tables.

Simulation results show that the two protocols have almost the same gain in throughput with a difference in network overload ("on-demand proxy discovery" is the best) and energy consumption ("greedy proxy discovery" is the best). The authors proposed also a secure mechanism to reward clients which participate in relaying process. A similar concept was discussed in [30].

Discussion: The authors proposed a complete study on the combination between cellular and ad hoc networks starting from the design of routing protocols until the suggestion of rewarding method for mobile relays. The use of two popular communication interfaces in the architecture (HDR and IEEE 802.11) is one of its strongest points. However, the authors focused decisions to choose proxy client on the throughput only, which may cause an overload at nodes that have a good downlink throughput. Furthermore, the authors did not consider proxy's and relays' energy autonomy in forwarding process. Indeed, even if a proxy client has a good downlink throughput, it should not accept relay requests if its energy level is low. Compared with other proposals that have addressed the same issue, authors in [29] propose the most complete study in terms of considered parameters and proposed solutions.

6) PBR [31]

This proposal presented an approach to consider the gain of mobile relays in MCN architecture compared to operator's gain.

The paper proposed a modification of DSR (dynamic source routing) protocol to use it in MCN architecture. The authors justified this choice by the low power consumption of DSR as it belongs to the family of reactive protocols (no exchange of messages to maintain routing tables). Indeed, the authors proposed a model that takes into consideration the gain of mobile relays compared to operator's gain. The parameter representing this gain is injected into DSR protocol route messages establishment.

The paper defined R_0 and C_0 respectively as revenue and cost of BS (operator) and, R_i and C_i revenue and cost of mobile i. From the principle that the gains of operator and mobile relays must be positive ($R_0-C_0> 0$ and $R_i-C_i> 0$), the proposal defined conditions on the maximum number of relays on a given path. This number will be transmitted in the route setup messages to the BS.

Discussion: The authors presented an interesting approach in the implementation of an ad hoc routing protocol in hybrid networks while taking into consideration rewarding of mobile relays. The drawback with this architecture is the use of only one interface to reach the BS that can limit the whole range of the cell.

7) JANUS [32]

The proposal dealt with hybrid networks using two interfaces: one is cellular (3G) and the other is ad hoc (802.11). The authors proposed a routing algorithm in this kind of networks that considers security constraints and compared it to UCAN proposal [29].

The proposed protocol contains two parts: a proactive part that involves the creation of the routing tree. This step keeps a path that ensures maximum throughput for a given mobile through the exchange of periodic messages. The second part of the protocol is the reactive part which consists of reserving a given path when the client wants to download data from the BS (Path booking step).

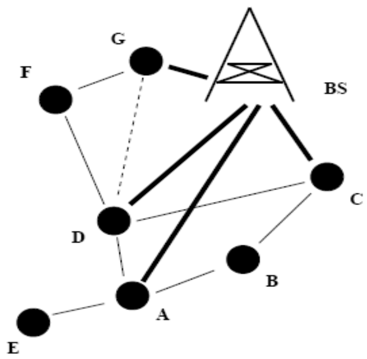

Fig. 7. Routing model in JANUS architecture [32].

Fig. 7 shows different links in JANUS architecture. The thicker and plain lines represent cellular and ad hoc links respectively. The dashed line represents an inexistent link called a tunnel.

The authors proposed by the end of the proposal comparative simulations between JANUS and UCAN [29], particularly in terms of the number of exchanged packets in cell and ad hoc parts. The authors pointed out the efficiency of JANUS method in terms of minimum number of packets exchanged in the cellular part. However, JANUS method becomes interesting in the ad hoc part only starting from a specific number of mobiles inside the network and a defined number of exchanged flows.

Discussion: The paper proposed a secure routing protocol for MCN networks against the most known attacks in ad hoc networks. The Proposed protocol also allows a minimal overhead in terms of the number of exchanged messages in the network before data transfer operation to or from BS. Nevertheless, compared with UCAN [6], the paper did not provide a complete protocol that takes into account rewarding of mobile relays. The authors did not consider also energy consumption of mobile relays in the path construction, which can have a detrimental impact on these mobiles.

8) MCN_Real time & best effort [33]

The paper proposed an original idea of combining 802.11 protocol with channel allocation method of cellular system. Indeed, the authors proposed the use of the 802.11 MAC layer for best-effort services (services that can tolerate packet loss) and cellular allocation channels for real-time services (e.g. voice services). The paper presented the BAAR protocol (base-assisted ad hoc routing) which is dedicated to establish routing path. The proposal focused on the important role of base station in this architecture. Indeed, control channels are continually exchanged between the BS and mobiles inside cell, these channels are used to transmit information related to routing path establishment (neighbors of each node) to the BS which keeps updated table with routing information.

The authors concluded the proposal with a plurality of simulations that show the gain of the MCN architecture compared to SCN architecture. The authors also proceeded to compare the proposed architecture to other architectures of literature addressing the same issue like iCAR [22] and HWN [34].

Discussion: The use of cellular channels for real time services ensures better service quality through multi-hop relays. Another advantage of the proposed architecture is that the BS controls the setting sessions (calls or data), this allows better error handling. The comparison of the proposed method's performance with other methods in the literature is a strong point of the paper also. However, the authors failed to specify a reward method of relays involved in the MCN mobile architecture. It should also be noted that using cellular channels for real time services implies the need for more network resources in terms of channels, particularly in terms of bandwidth for each mobile relay.

9) D2D [35]

The authors in this proposal presented a collection of various papers of literature that treated the D2D communication paradigm in cellular networks. The D2D communication is direct communication between two users without crossing the base station.

The first application of this concept was relaying in cellular networks. However, there are other applications to this paradigm such as content distribution, gaming and M2M communication.

The most important point to retain from this proposal is the classification of D2D communication according to the communication band used. Indeed, the authors distinguished two main families as illustrated in Fig. 8: inband D2D which consists of using cellular frequencies (licensed frequencies) and outband D2D using communication in free frequencies (ISM band).

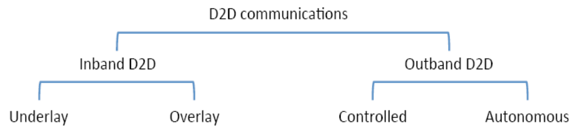

Fig. 8. D2D classification [35].

The authors distinguished two modes of inband communication. The first one, called underlay communication, consists in using the same frequency channels used in cellular part. The second mode, called overlay communication, is to dedicate special range of frequency channels to D2D communication.

They also distinguished two modes for outbound communication. The first one, "controlled" communication, allows BS to have control on D2D part (establishment of routing path, exchange control data ...). The second mode, "autonomous" communication, allows mobile in ad hoc part to handle communications autonomously.

Discussion: MCN networks are among the most common applications of D2D communication. The proposal presents the classification of D2D communication according to used frequencies. The major observation is that the most academic proposals lean towards the study of D2D communications in the licensed frequencies for reasons of reliability and efficient management of interferences. However, mobiles located in the dead spots of cell (indoor, cell border) are unable to communicate directly with the base station. A D2D communication in the licensed band in such cases is not possible, this lead to the need to use free frequencies and a distributed architecture that allow a mobile outside BS coverage to find a way through its neighbors to achieve BS.

D2D concept was discussed in [36].

10) ODMA [37]

ODMA (opportunity driven multiple access) was among the first proposals to enhance coverage in TDD (time-division duplex) UMTS system. The main purpose of ODMA is to reduce the overall transmission power in a system, to be resilient to shadowing and to potentially increase the coverage compared with single-hop transmission. All Mobile relays share the same cellular frequency bands to relay data packets.

Discussion: ODMA concept has a good capacity to enhance UMTS system. However, the proposal does not take into consideration some critical issues especially those related to rewarding of intermediate mobile relays. We can also invoke the difficulties to handle interferences in such system with all mobiles using the same frequency ranges.

11) xLoMM [16]

The paper is among the newest to propose suitable routing protocol for MCN architecture. Indeed, the authors tried to develop proposed solutions in [38] and propose the optimal value of *x* in xLoMM protocol.

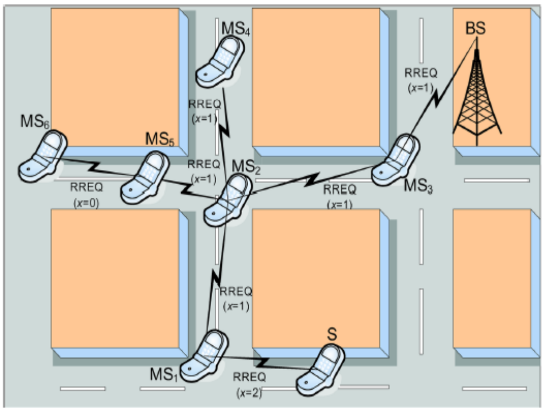

Fig. 9. MCN architecture with xLoMM routing [16]

The paper proposed through a multitude of simulations the optimum value of *x* that achieves a good packet delivery ratio while limiting the signaling ad-hoc rate, which reduces therefore energy consumption. As example in Fig. 9, the source node (S) launches a multi-hop route search process to reach the destination node (BS) allowing a maximum of 2 relaying nodes (*x*=2) that are not in the destination path. Although MS1 is further away from BS than node S, it is allowed to retransmit the RREQ packet at the expense of decreasing the '*x* permissions' field to 1.MS2 is then selected as a relaying node to retransmit the RREQ packet received from MS1 without reducing the '*x* permissions' field since it is closer to the BS than node MS1. From MS2, the RREQ packet is relayed through MS3, MS4 and MS5 nodes. However, the fact that only a maximum of 2 relaying nodes, that do not progress towards the destination node, are allowed in a multi-hop route search process by the xLoMM technique ensures that the multi-hop route search process will stop at node MS6.

The authors demonstrated that an optimum value of *x* depends on the deployment of the radio cell (microcell or macro cell). The authors showed through simulations that each time the cell radius increases, the permissive value of *x* should also be increased to achieve the optimum in terms of PDR (packet delivery ratio) and power consumption. Another parameter affecting the definition of the optimum value of *x* is the location of the source node. Indeed, a mobile in line of site with the BS does not require permissive value of *x* (*x* = 0) for optimal routing, unlike a mobile located at the intersection of roads which requires a greater permissive value of *x* to ensure optimal PDR with less energy consumption.

Discussion: The paper proposes a detailed study to optimize the permissive value of *x* in the xLoMM routing protocol. An optimum value of *x* will give the possibility to transfer data packets with a good delivery rate and with minimal energy consumption. However, the major drawback of the proposed architecture is the use of a single communication interface (802.11s) even with the BS. Such architecture could lead to enormous problems in macro cells especially regarding delivery time of data packets.

12) CAR [9]

The paper proposes a new approach for routing using D2D multi-hop concept. Authors propose a novel route discovery mechanism in which the route decision is the responsibility of BS for a given cell. The approach combine reactive and proactive route establishment in order to reduce the routing overhead.

Discussion: The authors propose an interesting architecture with multi-hop D2D routing to establish the link between two nodes. However, this work needs more steps before it can be considered for commercialization. In fact, all algorithms proposed in this paper need first to be validated by simulations, then more attention should be addressed to core network part in which adaptation for charging are needed. Finally, it's important to mention that the use case of this architecture will be limited since it supposes that all network nodes are under cell coverage.

13) D2D experimentation [39]

The article proposes an experimentation of the D2D concept through the use of 10 real mobiles in a laboratory (Fig. 10). The authors propose a distributed communication between mobiles using OLSR protocol to measure certain performances (Energy consumption, latency and the quality of the communication link).

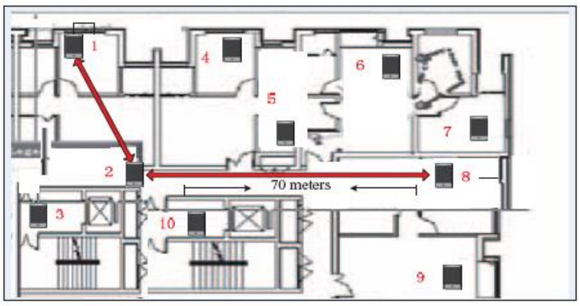

Fig. 10. Experimentation environment [39]

TABLE I. COMPARISON OF MCN ARCHITECTURES

Architecture name	Description	Routing frequency band in ad-hoc part	Interfaces to reach BS	Support charging & rewarding mechanism	Relay Nature	Routing strategy	Comment
MCN [26]	Using relaying architecture to reduce the number of BSs in cellular network and enhance system capacity.	ISM bands (802.11)	single interface	NO	Mobile relay	Centralized routing	Using only one interface with 802.11 to reach BS is not useful since it needs more hops
iCAR [22]	Using fixed relays to overcome congestion issue in cellular networks	ISM bands	Dual interfaces	NO	Fixed relays (ARS)	Centralized routing	Introduction of ARS in the network will introduce more cost for operators
AGSM [27]	Combine GSM and MANET to improve cellular coverage in dead spots	GSM bands	Dual interfaces	NO	Mobile relay	Distributed routing	*Proposal limited to voice services only. * No proposal of routing mechanism (only one hop communication)
CRS [28]	Charging and rewarding solution for MCN	-	-	YES	Mobile relay	-	No explanation about used communication interfaces and how the proposed solution can be implemented inside it.
UCAN [29]	Combine cellular and ad hoc network to increase the downlink throughput	ISM bands (802.11)	Dual interfaces	YES	Mobile relay	Distributed routing	Proxy load and autonomy are not taken into consideration in path selection metrics
PBR [31]	Take into consideration hops profit in MCN architecture	-	single interface	YES	Mobile relay	Distributed routing	Using only one interface with 802.11 to reach BS with limited number of hops should limit the BS range also.
JANUS [32]	Combine cellular and ad hoc network through a secure routing protocol	ISM bands (802.11)	Dual interfaces	NO	Mobile relay	Distributed routing	MS autonomy is not taken into consideration in path selection metrics
MCN_AP [33]	Proposes MCN architecture to increase QoS of data and voice services	Licensed & unlicensed bands	single for real time services Dual for data services	NO	Mobile relay	Centralized routing	Using only one interface with licensed bands and relays increase the need of more cellular resources
D2D [35]	Direct communication between two mobiles that can occur on cellular spectrum or unlicensed spectrum.	Licensed & unlicensed bands	single and dual interface	NO	Mobile relay	Centralized routing	The multi-hop communication is done in only one hop, which may limit the usage of D2D architecture
ODMA [37]	Relay transmission protocol that allows to maintain high data rate in the edges of TDD coverage	UMTS TDD bands	Single interface	NO	Mobile relay	Centralized routing	Interference issues need to be studied since the protocol uses the same frequency band of cellular network (UMTS TDD)
xLoMM [16]	Proposes efficient multi metrics routing protocol for MCN architecture	ISM bands (802.11)	Single interface	NO	Mobile relay	Distributed routing	Using only 802.11 interface to reach the BS may cause lot of delay for macro cells.
CAR [9]	Routing approach combining reactive and proactive route establishment.	Licensed bands	Single interface	No	Mobile relay	Centralized routing	All mobiles should be under cell coverage. Method needs to be validated by simulations.
D2D experiment-ation [39]	Proposes experimentation of multi-hop D2D using OLSR protocol.	ISM bands (802.11)	Single interface	No	Mobile relay	Distributed routing	Experimentation was limited to adhoc part of MCN architecture without including 4G/5G BS.

Through a series of measurements, the authors show the improvement of some communication performances using the D2D concept. Indeed, it is shown that this communication can significantly improve the latency and quality of the network link compared to direct communication.

Discussion: An interesting experimentation is proposed through this paper. This experimentation is the first in the field of D2D communications. However, the work does not highlight a D2D communication in a real environment with the presence of a 4G or 5G base station. The work is therefore limited to the experimentation of the ad hoc part of the D2D networks.

B. Comparison of Proposed Architectures

We present in this section a comparison table of the discussed MCN architectures following the main classification factors presented in Section 2 and basing on the discussion and analysis developed in Section III A (see Table I).

IV. Research Challenges

As stated, MCN paradigm is a complete approach that takes into consideration not only routing issues to ensure the communication but also other important aspects [40]. Charging and rewarding are among of the most challenging issues in MCN. In fact, charging inside cellular networks is ensured via intelligent network platform. However, this mechanism looks complicated in MCN architecture since it should handle rewarding of mobile relays that contributes in routing communication. The issue was treated partially in some proposals in the literature [28], [29], [31].

Another challenging issue in MCN architecture is reducing the system power consumption. In fact, MCN communication may decrease energy consumption of source node [41] as it may use communication technology with less energy consumption (IEEE 802.11 for example). However, power consumption of relay nodes should be taken into consideration by using suitable protocols in ad hoc part that decrease the number of control messages. This issue was partially addressed in [42]-[45].

One more challenging issue inside MCNs is the minimum delay channel assignment. In fact, for architectures that use cellular bands for relay communication, channel assignment approach may directly have an impact upon end to end communication delay. This issue was partially addressed in [46], [47], [43].

High user mobility is also an important challenging issue in MCN architecture. In fact, user mobility may increase link failure and handoff resulting in frequent route update and reassignment of channels which can considerably impact system energy. This issue was partially addressed in [48].

Security is also one of the challenging aspects to design a complete MCN architecture. Like ad hoc networks, security in MCNs is a serious issue that should be taken into consideration for a complete MCN proposal. However, unlike ad hoc networks MCNs have a centralized authority for registration process. This gives MCN better ability in preventing and detecting security attacks. The issue was partially addressed in [49]-[50].

V. Conclusions

MCN may constitute one of the best solutions to enhance performance of cellular systems and improve the quality of telecommunication provided services in terms of throughput and coverage. In this survey, we introduced the MCN concept with the main classification factors of proposed state of the art architectures. As stated, the key classification factor of MCN proposal is the frequency band used in ad-hoc part. The importance of this factor comes from the huge economics that can be gained when ISM bands are used. However, these bands suffer from degraded QoS because of the difficulties to handle interferences. Such bands can be then used for best effort services that may tolerate packet loss. It is important to mention also that security in ad hoc part is one of the most challenging field in MCN architecture. Also, a performed routing protocol that considers energy consumption and rewarding of relays may have a good performance inside MCN architecture.

List of Acronyms

AODV	Ad hoc on demand distance vector
ARS	Adhoc relay station
BTS	Base transceiver station
CAR	Centralized adaptive routing
CPU	Central processing unit
D2D	Device to device
DSR	Dynamic source routing
FR	Fixed relay
GPS	Global positioning system
GSM	Global system for mobile communications
ICAR	Integrated cellular and Ad hoc relay
ISM	industrial, scientific and medical
LTE	Long term evolution
M2M	Machine to machine
MAC	Media access control
MANET	Mobile Ad hoc network
MCN	Multihop cellular network
MR	Mobile relay
ODMA	Oportunity driven method access
RTREQ	Route request
SCN	Single-hop cellular network
TDD	Time division duplex
WLAN	Wireless local area network

References

[1] C. Liu and B. Natarajan, "Average achievable throughput in D2D underlay networks," in *Proc. IEEE Conf. on Computer Communications Workshops*, April 2016, pp. 118-123.

[2] M. Ni and J. Pan, "Throughput analysis for downlink resource reusing D2D communications in cellular networks," in *Proc. IEEE Global Communications Conf.*, Dec. 2017, pp. 1-7.

[3] Y. Hwang, J. Park, K. W. Sung, and S. L. Kim, "On the throughput gain of device-to-device communications," *ICT Express*, vol. 1, no. 2, pp. 67-70, 2015.

[4] J. Gui and K. Zhou, "Cellular throughput optimization by game-based power adjustment and outband D2D communication," *EURASIP J. Wireless Commun. Netw.*, vol. 2018, no. 1, p. 254, Oct. 2018.

[5] H. Sun, M. Wildemeersch, M. Sheng, and T. Q. Quek, "D2D enhanced heterogeneous cellular networks with dynamic TDD," *IEEE Trans. Wireless Commun.*, vol. 14, no. 8, pp. 4204-4218, Aug. 2015.

[6] H. Y. Hsieh and R. Sivakumar, "On using the ad-hoc network model in cellular packet data networks," in *Proc. ACM MobiHoc*, Lausanne, Switzerland, 2002, pp. 36–47.

[7] A. Ramamurthy, V. Sathya, S. Ghosh, A. Franklin, and B. R. Tamma, "On improving capacity of full-duplex small cells with D2D," in *Proc. Submitted to IEEE Globecom Conference*, June 2016.

[8] Y. H. Tam, H. S. Hassanein, and S. G. Akl, "A study of multi-hop cellular networks," *Wireless Commun. Mobile Comput.*, vol. 12, no. 12, pp. 1115-1129, 2012.

[9] F. S. Shaikh and R. Wismuller, "Centralized adaptive routing in multihop cellular D2D communications," presented at the 2nd Int. Conf. on Computer and Communication Systems, 2017.

[10] P. Ren, Q. Du, and L. Sun, "Interference-aware routing for hop-count minimization in wireless D2D networks," in *Proc. IEEE/CIC Int. Conf. on Communications in China-Workshops*, 2013, pp. 65–70.

[11] Y. H. Tam, R. Benkoczi, H. S. Hassanein, and S. G. Akl, "Channel assignment for multihop cellular networks: Minimum delay," *IEEE Trans. on Mobile Computing*, vol. 9, no. 7, pp. 1022-1034, 2010.

[12] X. J. Li and P. H. J. Chong, "Performance analysis of multihop cellular network with fixed channel assignment," *Wireless Networks*, vol. 16, pp. 511-526, Feb. 2010.

[13] R. Wang, J. Zhang, S. H. Song, and K. B. Letaief, "Optimal QoS-aware channel assignment in D2D communications with partial CSI," *IEEE Trans. Wireless Commun.*, vol. 15, pp. 7594-7609, Nov. 2016.

[14] S. N. Swain, S. Mishra, and C. S. R. Murthy, "A novel spectrum reuse scheme for interference mitigation in a dense overlay D2D network," in *Proc. IEEE 26th Annu. Int. Symp. Personal Indoor Mobile Radio Commun.*, 2015, pp. 1201-1205.

[15] M. J. Miller, W. D. List, and N. H. Vaidya, "A hybrid network implementation to extend infrastructure reach," *Tech. Rep*., University of Illinois-Urbana-Champaign, 2003.

[16] B. Coll-Perales and J. Gozalvez, "Contextual optimization of location-based routing protocols for multi-hop cellular networks using mobile relays," *Telecommunication Systems*, April 2015, pp. 1572-9451.

[17] D. Zhao and T. D. Todd, "Cellular CDMA capacity with out-of-band multihop relaying," *IEEE Trans. Mobile Comput*., vol. 5, no. 2, pp. 170–178, Feb. 2005.

[18] B. Liu, P. Thiran, and D. Towsley, "Capacity of a wireless ad hoc network with infrastructure," in *Proc. ACM MobiHoc*, Montreal, PQ, Canada, 2007, pp. 239–246.

[19] M. Jakobsson, J. P. Hubaux, and L. Buttyan, "A micro-payment scheme encouraging collaboration in multi-hop cellular networks," in *Proc. Seventh Int. Financial Cryptography Conf*., 2003, pp. 27-30.

[20] J. Zhou and Y. Yang, "Parcels: Pervasive ad-hoc relaying for cellular systems," in *Proc. 1st Annual Mediterranean Ad Hoc Networking Workshop*, Sardegna, Italy, September 2002, pp. 1-6

[21] J. Gozalvez and B. Coll-Perales, "Experimental evaluation of multi-hop cellular networks using mobile relays," *IEEE Communications Magazine*, vol. 51, no. 7, pp. 122-129, Jul. 2013.

[22] H. Wu, C. Qiao, S. De, and O. K. Tonguz, "Integrated cellular and ad-hoc relay systems: iCAR," *IEEE J. Sel. Areas Commun*., vol. 19, no. 10, pp. 2105-2115, Oct. 2001.

[23] M. Lott, M. Weckerle, W. Zirwas, H. Li, and E. Schulz. "Hierarchical cellular multihop networks," in *Proc. Fifth European Personal Mobile Communications Conf*., March 2003, pp. 37-43.

[24] Ioannidis, B. Carbunar, and C. Nita-Rotaru, "High throughput routing in hybrid cellular and ad-hoc networks," in *Proc. Sixth IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks*, 2005, pp. 171–176.

[25] H. Viswanathan and S. Mukherjee, "Performance of cellular networks with relays and centralized scheduling," in *Proc. IEEE Veh. Technol. Conf.*, 2003, pp. 1923–1928.

[26] Y. D. Lin and Y. C. Hsu, "Multihop cellular: A new architecture for wireless communications," *Proc. IEEE INFOCOM*, vol. 3, pp. 1273-1282, 2000.

[27] G. N. Aggelou and R. Tafazolli, "On the relaying capability of next-generation GSM cellular networks," *IEEE Personal Communications*, vol. 8, no. 1, pp. 40–47, 2001.

[28] N. B. Salem, L. Butty án, J. P. Hubaux, and M. Jakobsson, "A charging and rewarding scheme for packet forwarding in multi-hop cellular networks," in *Proc. 4th ACM Int. Symp. on Mobile Ad Hoc Networking & Computing*, 2003, pp. 13-24.

[29] H. Luo, R. Ramjee, P. Sinha, L. Li, and S. Lu, "UCAN: A unified cellular and ad hoc network architecture," in *Proc. 9th Annual Int. Conf. on Mobile Computing and Networking*, 2003, pp. 353-367.

[30] R. Bhatia, L. Li, H. Luo, and R. Ramjee, "ICAM: Integrated cellular and ad hoc multicast," *IEEE Trans.* on *Mobile Computing*, vol. 5, no. 8, pp. 1004–1015, Aug. 2006.

[31] Y. J. Choi, J. H. Jun, and S. Bahk, "Profit-based routing for multihope coverage extension in wireless networks," *Wireless Personal Communications*, vol. 42, no. 4, pp. 465-478, 2007.

[32] B. Carbunar, I. Ioannidis, and C. NitaRotaru, "JANUS: Towards robust and malicious resilient routing in hybrid wireless networks," in *Proc. 3rd ACM Workshop on Wireless Security*, 2004, pp. 11–20.

[33] B. S. Manoj, R. Ananthapadmanabha, and C. S. R. Murthy, "Multi-hop cellular networks: Architecture and protocols for best-effort and real-time communication," *Journal of Parallel and Distributed Computing*., vol. 65, no. 6, pp. 767-791, June 2005.

[34] H. Y. Hsieh and R. Sivakumar, "Performance comparison of cellular and multi-hop wireless networks: A quantitative study," presented at ACM SIGMETRICS, June 2001.

[35] D. Feng, L. Lu, Y. Yuan-Wu, G. Li, S. Li, G. Feng, "Device-to-device communications in cellular networks," *IEEE Commun. Mag.*, vol. 52, no. 4, pp. 49-55, Apr. 2014.

[36] P. Gandotra, R. K. Jha, and S. Jain, "A survey on device-to-device (D2D) communication: Architecture and security issues," *J. Netw. Comput. Appl.*, vol. 78, pp. 9-29, Jan. 2016.

[37] Third Generation Partnership Project (3GPP), Technical Specification Group Radio Access Network, Opportunity Driven Multiple Access (ODMA), Sophia Antipolis, Valbbonne (3G TR 25.924 Version 1.0.0), 1999.

[38] B. Coll-Perales and J. Gozalvez, "Energy efficient routing protocols for multi-hop cellular networks," in *Proc. 20th IEEE Personal Indoor and Mobile Radio Communications*, Japan 2009, pp. 1457–1461.

[39] H. Qin, Z. Mi, C. Dong, F. Peng, and P. Sheng, "An experimental study on multihop D2D communications based on smartphones," in *Proc. IEEE 83rd Vehicular Technology Conf*., 2016, pp. 1–5.

[40] D. Cavalcanti, D. Agrawal, C. Cordeiro, B. Xie, and A. Kumar, "Issues in integrating cellular networks WLANs, and MANETs: A futuristic heterogeneous wireless network," *IEEE Wireless Communications*, vol. 12, no. 3, pp. 30-41, June 2005.

[41] C. L Évy-Bencheton and G. Villemaud, "Optimisation de la consommation dans les relais mobiles multi-modes," presented at 10 èmes Journ ées Doctorales en Informatique et R éseaux, 2009.

[42] Z. Jingyi, L. Xi, and X. Quansheng, "Multi-hop routing for energy efficiency enhancement in relay-assisted device-to-device communication," *The Journal of China Universities of Posts and Telecommunications*, vol. 22, no. 2, pp. 1–51, 2015.

[43] Z. Zhou, K. Ota, M. Dong, and C. Xu, "Energy-efficient matching for resource allocation in D2D enabled cellular networks," *IEEE Trans.* on *Vehicular Technology*, vol. 66, no.6, pp. 5256-5268, 2017.

[44] M. I. Khalil, S. M. Berber, and K. W. Sowerby, "Energy efficiency and spectrum efficiency balance of wireless relay networks," in *Proc. 8th IEEE Int. Conf. on Communication Software and Networks*, 2016, pp. 397-401.

[45] M. H¨oyhty¨a, O. Apilo, and M. Lasanen, "Review of latest advances in 3GPP standardization: D2D communication in 5G systems and its energy consumption models," *Future Internet*, vol. 10, no. 1, p. 3, 2018.

[46] Y. H. Tam, R. Benkoczi, H. S. Hassanein, and S. G. Akl, "Optimal channel assignment in multi-hop cellular networks," *IEEE GLOBECOM*, pp. 731-735, November 2007.

[47] F. Hussain, M. Y. Hassan, M. S. Hossen, and S. Choudhury, "An optimal resource allocation algorithm for D2D communication underlaying cellular networks," presented at the 14th Annual IEEE Consumer Communications & Networking Conf., Jan. 2017.

[48] D. Wu, L. Zhou, Y. M. Cai, and R. Q. Y. Hu, "The role of mobility for D2D communications in LTE-advanced networks:

Energy vs. bandwidth efficiency," *IEEE Wireless Communication Magazine*, vol. 21, no. 2, pp. 67-71, 2014.

[49] P. Gandotra, R. K. Jha, and S. Jain, "A survey on device-to-device (D2D) communication: Architecture and security issues," *Journal of Network and Computer Applications*, vol. 78, no. C, pp. 9–29, 2017.

[50] M. Wang and Z. Yan, "A survey on security in D2D communications," *Mobile Networks and Applications*, vol. 22, no. 2, pp. 195–208, 2017.

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