International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

Q.5022

(04/2020)

SERIES Q: SWITCHING AND SIGNALLING, AND ASSOCIATED MEASUREMENTS AND TESTS

Signalling requirements and protocols for IMT-2020 – Protocols for IMT-2020

Signalling procedure of energy efficient device-to-device communication for IMT-2020 networks

Recommendation ITU-T Q.5022

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Recommendation ITU-T Q.5022

Signalling procedure of energy efficient device-to-device communication for IMT-2020 networks

Summary

According to different surveys, the number of wireless devices may reach trillions by 2020. The massive increase of wireless devices will lead to different interconnection and communication challenges. In this regard, most wireless devices would need to use device-to-device (D2D) communication.

In general, D2D communication may bring additional benefits to new wireless devices such as higher throughput, better cell coverage, spectrum efficiency and other valuable features of the cellular networks.

However, there is still a need to specify a procedure which may switch between two algorithms used for D2D communication according to the cell status, as follows:

– communication algorithm which is used in a stable condition of the cell,

– communication algorithm which is used in the situation when the serving base station (BS) becomes unavailable at certain periods of time.

This procedure should be based on an energy efficient intra-cell clustering and the procedure should be able to reuse frequency between clusters. The key advantage of the procedure is the reducing of the signalling overhead.

Recommendation ITU-T Q.5022 describes a D2D communication procedure to be used as a part of the IMT-2020 control plane.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Q.5022	2020-04-29	11	11.1002/1000/14246

Keywords

Clustering, device-to-device communication, procedure, signalling, IMT 2020.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

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NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Recommendation ITU-T Q.5022

Signalling procedure of energy efficient device-to-device communication for IMT-2020 networks

1 Scope

This Recommendation describes the procedure for device-to-device (D2D) communication based on energy efficient intra-cell clustering and the ability to reuse frequencies between intra-cell clusters. The aim of this procedure is to enable D2D communication in different conditions (normal mode and failure mode) in IMT-2020 network, including clustering in cell, switching between different modes, signalling for node discovery, and communication with neighbour cells.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

None.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 software-defined networking [b-ITU-T Y.3300]: A set of techniques that enables to directly program, orchestrate, control and manage network resources, which facilitates the design, delivery and operation of network services in a dynamic and scalable manner.

3.1.2 network virtualization [b-ITU-T Y.3011]: A technology that enables the creation of logically isolated network partitions over shared physical networks so that heterogeneous collections of multiple virtual networks can simultaneously coexist over the shared networks. This includes the aggregation of multiple resources in a provider and appearing as a single resource.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

B-CH Boundary Cluster Head

BS Base Station

CH Cluster Head

CM Cluster Members

CSMA Carrier Sense Multiple Access

D2D Device to Device

IMSI	International Mobile Subscriber Identity
MEC	Mobile Edge Computing
MLHC	Multilevel Hierarchical Clustering
NFC	Near Field Communication
NFV	Network Function Virtualization
QoS	Quality of Service
SDN	Software Defined Networking
TDMA	Time Division Multiple Access
TMSI	Temporary Mobile Subscribe Identity
UE	User Equipment
UWB	Ultra Wide Bandwidth

5 Conventions

None.

6 Overview

Benefits of D2D – IMT-2020:

The proposed procedure can be employed in the bottom layers of the IMT-2020 (data plane network function and resources). Besides, D2D – IMT-2020 provides the best way for integrating wireless sensors and other wireless devices into the cellular network, it also adds several benefits to the IMT-2020 system performance.

1 – Spectrum efficiency (resources efficiency):

Employing device to device (D2D) communication with frequency reuse and proper interference management increases the spectrum efficiency of IMT-2020 system.

2 – Power efficiency:

The proposed procedure stack increases the power efficiency of the IMT-2020 system by applying energy efficient clustering scheme.

3 – Data rate:

D2D – IMT-2020 achieves the high data rate required from the IMT-2020 by improving radio resources utilization.

4 – Traffic congestion:

D2D – IMT-2020 provides a way for offloading cellular traffic by introducing direct paths and thus reduces the traffic congestion anticipated from IMT-2020.

5 – System coverage:

D2D – IMT-2020 achieves higher availability and reliability of the system and thus increases the system coverage to a higher level.

In this Recommendation:

Normal operation mode is the network operation mode in which the base station (BS) works well and leads all the communication processes in the cellular cell. In this mode, the BS controls and monitors both types of communication (cellular and D2D) run inside the cellular cell.

Failure operation mode is the network operation mode in which the inter-cell communication is maintained using D2D communication. If the BS goes into failure, the communication inside the cell takes place using D2D communication and multi-level clustering.

Mode selection is the process of selecting the transmission mode if it will be a D2D or a cellular.

Clustering of wireless devices is the way in which wireless nodes are organized into groups or clusters according to specific properties of nodes and network requirements. The leader of each group of nodes or cluster is known as the cluster head (CH) and the other non-CH nodes are known as member nodes. Each CH acts as the local coordinator of transmissions within its cluster (i.e., intra-cluster communication) and also communicates with other cluster heads or with the base station (i.e., inter-cluster communication).

7 Features of energy efficient D2D communication procedure

7.1 Architecture and methodology

This procedure switches between two modes based on the network status. The first mode is the normal mode, which works as long as the network operation is in the normal situation, therefore the cell employs the normal mode when the BS works well. For the failure situations, the second mode is employed and thus it is defined as the failure mode. If the BS goes into failure due to a technical problem or a catastrophic situation the cell employs the failure mode. The network employs an intelligent core network based on software defined networking (SDN), network function virtualization (NFV) and mobile edge computing (MEC). Figures 7-1 and 7-2 illustrate the network topology in both modes while the mechanisms of clustering in the two modes are totally different.

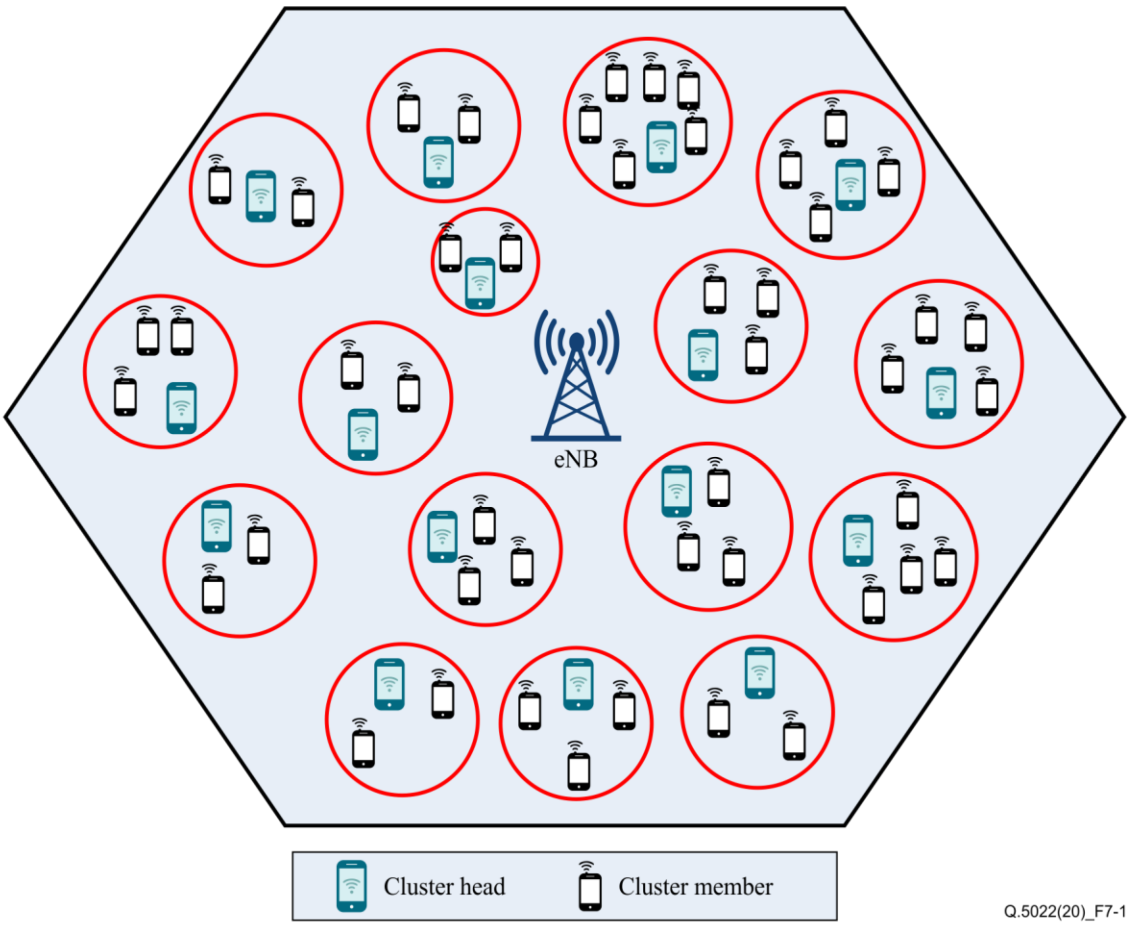

Figure 7-1 – Network topology in normal mode

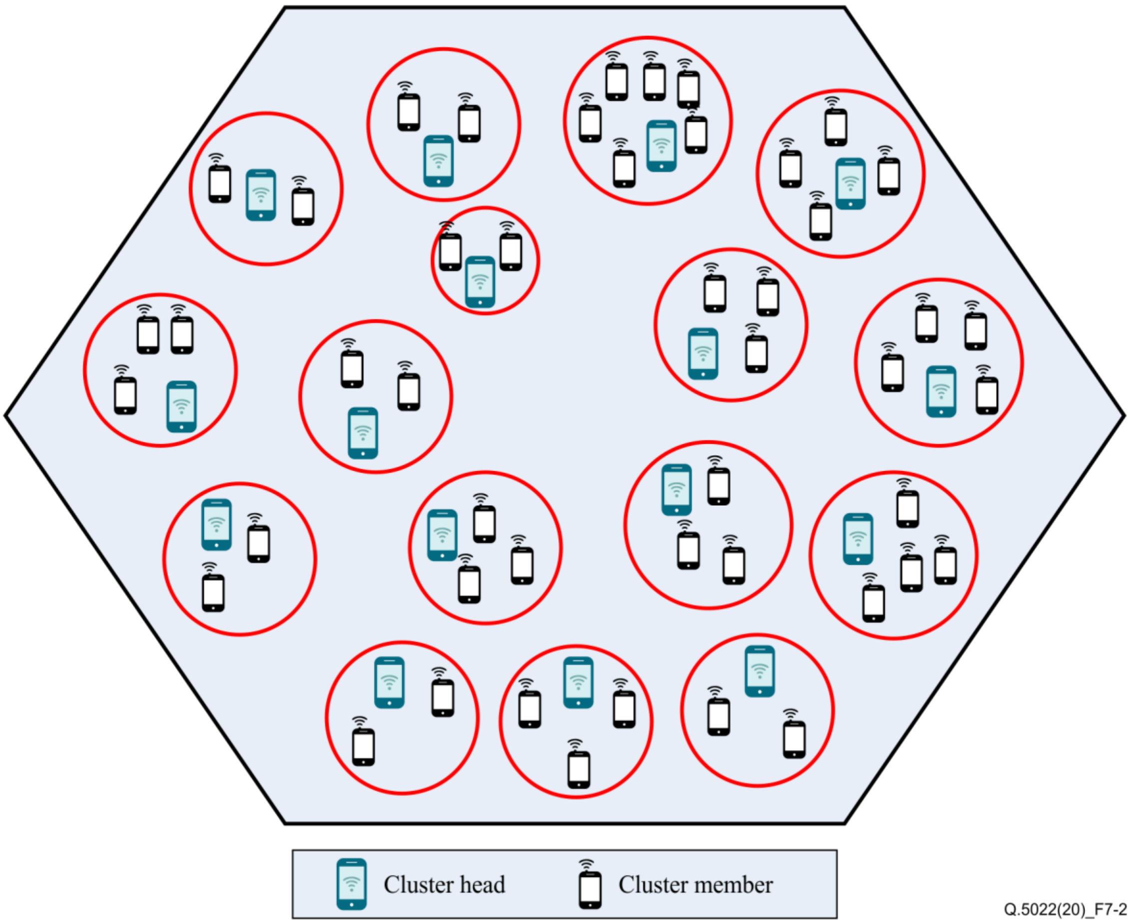

Figure 7-2 – Network topology in failure mode

7.2 Cluster formation in normal mode

In normal mode, the network employs an in-band underlay D2D communication. In the in-band underlay D2D communication user equipment (UEs) close to each other are able to exchange data through a cellular direct link without transmitting and receiving to the BS. The BS performs an intra-cell clustering and forms many clusters. The BS selects cluster heads and constructs clusters based on the game theory. Each cluster has a cluster head and cluster members (CMs); and the communication between CMs and CH is established via direct link. After cluster formation, the resources are distributed by the BS. A portion of the cell bandwidth is dedicated to the D2D communication inside clusters. This part of the spectrum is shared by the clusters with the employing of frequency reuse. Figure 7-1 illustrates the network structure in this mode and Figure 7-3 shows the employment of frequency reuse mechanism between intra-cell clusters.

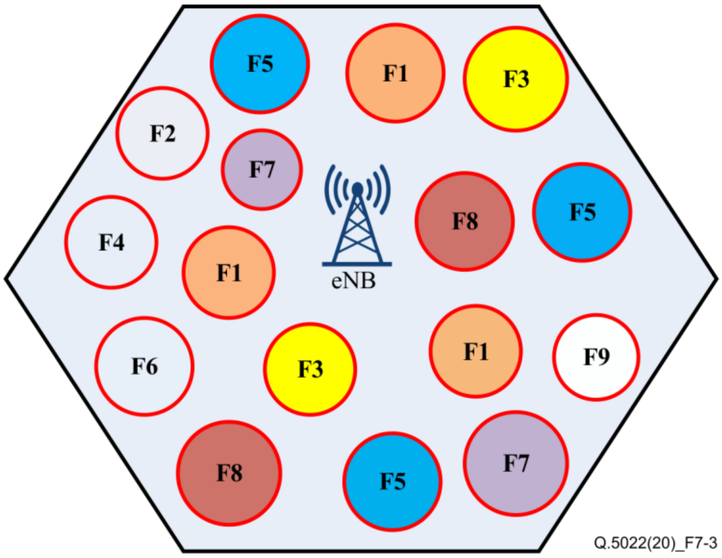

Figure 7-3 – The cell under normal mode

7.3 Signalling and connection set up in normal mode

The proposed structure of clustering with in-band D2D communication reduces the signalling overhead to the information data due to the existence of CHs that lead all the communication processes inside clusters.

Similar to the existing technologies of short-range wireless transmission (e.g., Wi-Fi direct, Bluetooth, near field communication (NFC) and ultra wide bandwidth (UWB)), the in- band D2D communications achieve a low transmission delay. Moreover, because of the use of licensed spectrum, the in-band D2D communication significantly increases the spectral efficiency, achieves high quality of service (QoS), offloads traffic, as well as achieves better system energy efficiency. The proposed in-band D2D signalling procedure for normal mode consists of two phases: Discovery phase and Communication phase.

7.4 Discovery phase

The discovery process is generally the main process for any type of D2D communication as the devices should first discover that they are in proximity with each other. The main advantage of involving network in the discovery process is to conserve the energy of the devices, provide higher latency efficiency and make the process more user friendly for the end user. The discovery is the first step to establish a D2D communication process. This process contains all the signalling between BS and UEs to establish a connection and set up clusters. Resource allocations by the BS to CHs are a part of this phase. Two discovery processes are applied in the procedure, one for discovering CHs (major discovery) and the other for discovering CMs (minor discovery).

Major discovery:

The major discovery process can be classified into two main categories as indicated in Figure 7-4. The first classification is from the network point of view and it can be classified as: a light BS control and a tight BS control. In the light BS control, the BS periodically broadcasts a set of available resources that can be used by CHs to transmit and receive the discovery beacon. While for the tight BS control, the BS solicits users who want to be CHs to transmit their discovery beacon.

The second classification is from the user point of view and the discovery process can be seen as: Open discovery or restricted discovery. In the open discovery, all devices are available and can be detected and involved in the D2D communication process. For the other, the restricted discovery allows users to permit or prevent the D2D signalling requests.

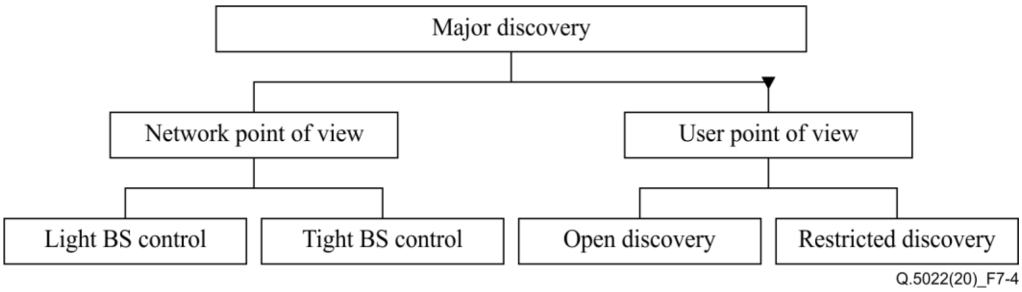

Figure 7-4 – Classifications of major discovery process

For this mode of operation of the proposed signalling procedure, the light BS control was selected to act as the major discovery mode. Thus, users who want to be CHs send or receive the discovery beacon via the broadcasted resources. Figure 7-5 illustrates the signalling steps for the major discovery process. The main advantage of this discovery approach is the extremely low signalling overhead compared to other discovery methods. BS allocates resources for each CH and plays an important role in transmission format selection for each cluster (e.g., mode selection of multi-antenna transmission, modulation scheme and coding), mode selection, power control and scheduling.

Minor discovery:

Here the signalling procedure employs a direct discovery based on the steps indicated in Figures 7-6 and 7-7. CHs broadcast a discovery signal for CMs discovery. CMs respond to the discovery signal and then exchange the identities with the CH.

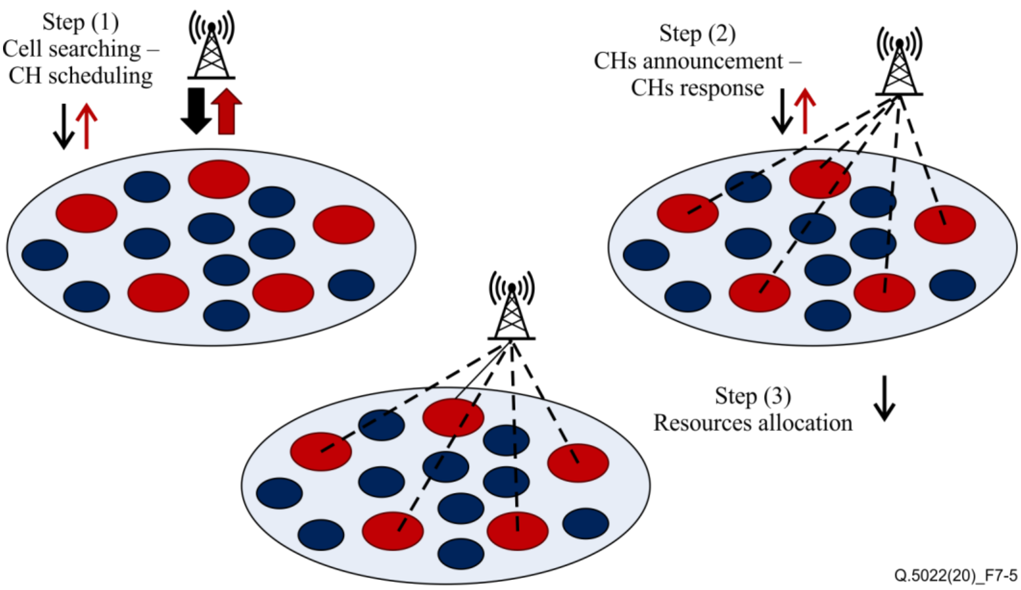

Figure 7-5 – Major discovery signalling steps

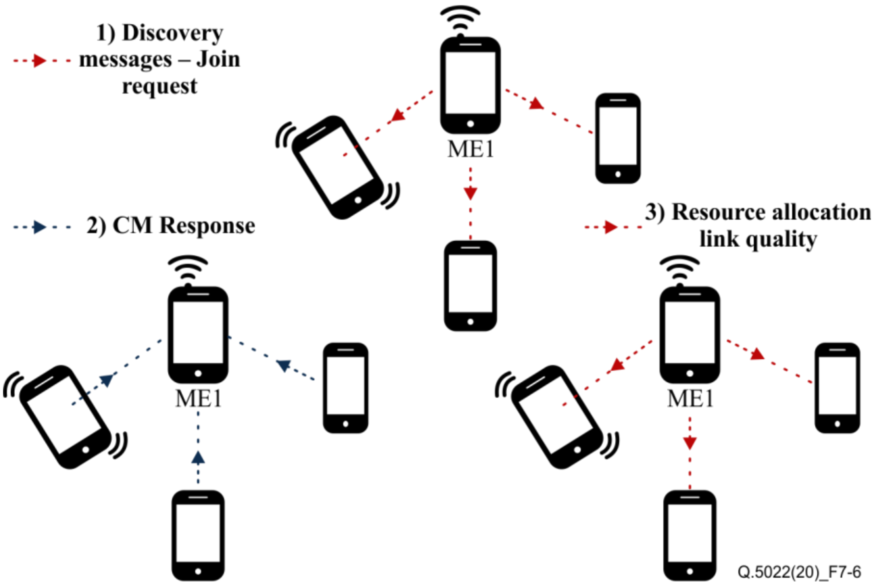

Figure 7-6 – Minor discovery signalling steps

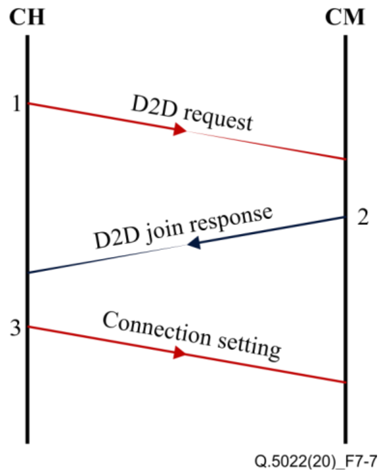

Figure 7-7 – Signalling diagram for minor discovery stage

Figure 7-8 shows a flow chart that summarizes the multilevel hierarchical clustering (MLHC) operation.

This stage consists of two phases, set-up phase and steady state phase.

- Set-up phase:

In the set-up phase, each node decides whether or not to be a cluster-head based on its residual energy and a globally pre-established percentage of cluster heads. The cluster head election process will be the nodes that elect themselves as a cluster head that broadcast an announcement message announcing themselves as cluster heads.

The member nodes (non-cluster head nodes) receive the advertisement message from the cluster heads and may possibly receive multiple messages from multiple cluster heads. It selects only one cluster to join based on the signal strength of the received message from the corresponding cluster-head.

To join a cluster, a member node prepares a join message and sends it to the selected cluster head in accordance with the time division multiple access (TDMA) schedule to know when to send it to the cluster head. The join message is a short message which contains the member node's identification number (ID) and the cluster head ID. Each CH receives messages from other non-CH nodes that are decided to join its cluster and thus clusters are formed. After that, each CH creates a TDMA schedule for the nodes in its cluster, allocating each node a time slot to use for sending data.

The TDMA schedule is used to:

– Avoid the collisions of data sent by member nodes,

– Put the member nodes in sleep mode (i.e., turn off the radio transmission components of the sensor node) for a long period of time, and in active mode (i.e., the radio transmission component of sensor is on) only during the transmission time. This will reduce the energy dissipation and save the sensor's battery.

– Each CH broadcasts its TDMA schedule and each member node receives the schedule of its CH. At this point the set-up phase is completed, and the next phase begins. All messages in this phase are broadcasted using carrier sense multiple access (CSMA) MAC protocol.

Three level hierarchy (MLHC)

In MLHC, the network operation is divided into rounds; each round consists of three stages with two phases for each stage as shown in Figure 7-8. Each stage corresponds to a clustering level.

Stage (1): The first level of clustering

This stage is the same as the first stage of MLHC. It consists of two phases, set-up phase and steady state phase. Similar to what happens in the first stage of MLHC, the nodes are organized into clusters with one CH for each cluster. The selection of cluster heads is done in the same way as in MLHC and the duration of the set-up phase and the steady state phase are the same as in MLHC. Each CH organizes the communication in its cluster and collects the sensed data from the member nodes. It also aggregates the collected data removing any redundancy in it.

Stage (2): The second level of clustering

In this stage, a second level of clustering is performed in the same manner as that of the second stage of MLHC. This stage consists of two phases, the set-up phase and the steady state phase.

In the setup phase, the CHs of the first stage are grouped into clusters with a leader of each cluster (L_2-CH). The L_2-CHs are chosen from the CHs of the first stage in the same manner as in MLHC. Each L_2-CH creates a TDMA schedule for the CH nodes in its cluster to inform them when they can send their data.

In the steady state phase, the CH nodes send their data to the L_2-CHs based on the broadcasted TDMA schedule. L_2-CHs receive the data and aggregate it to remove any redundancy.

Stage (3): The third level of clustering

In this stage, a third clustering is performed between L_2-CHs of the second stage. L_2-CHs do not send their data directly to the base station but they elect some of them known as the third level cluster heads and denoted as L_3-CHs. L_2-CHs are organized into clusters with a coordinator for each cluster (L_3-CH). The L_3-CHs are responsible for collecting data from the L_2-CHs and sending it to the base station.

The third level of clustering achieves energy reduction as the distance to the base station is reduced and the number of nodes sent to the base station is reduced. This stage is like other stages, consisting of two phases, i.e., the set-up phase and steady state phase.

In the set-up phase, the third level of clusters is constructed, and the L_3-CHs are chosen. The election of L_3-CHs is based on the residual energy of each L_2-CH node, the distance to the base station and the pre-established percentage of the L_3-CHs as will be discussed. In the steady-state phase, each L_2-CH node sends its aggregated data to the corresponding L_3-CH based on the allocated TDMA schedule that each one sends during its allocated time slot. L_3-CHs receive data from L_2-CHs and depending on the application of the network, L_3-CHs may aggregate the received data if it contains any redundancy to conserve more energy. Finally, L_3-CHs send their data directly to the base station.

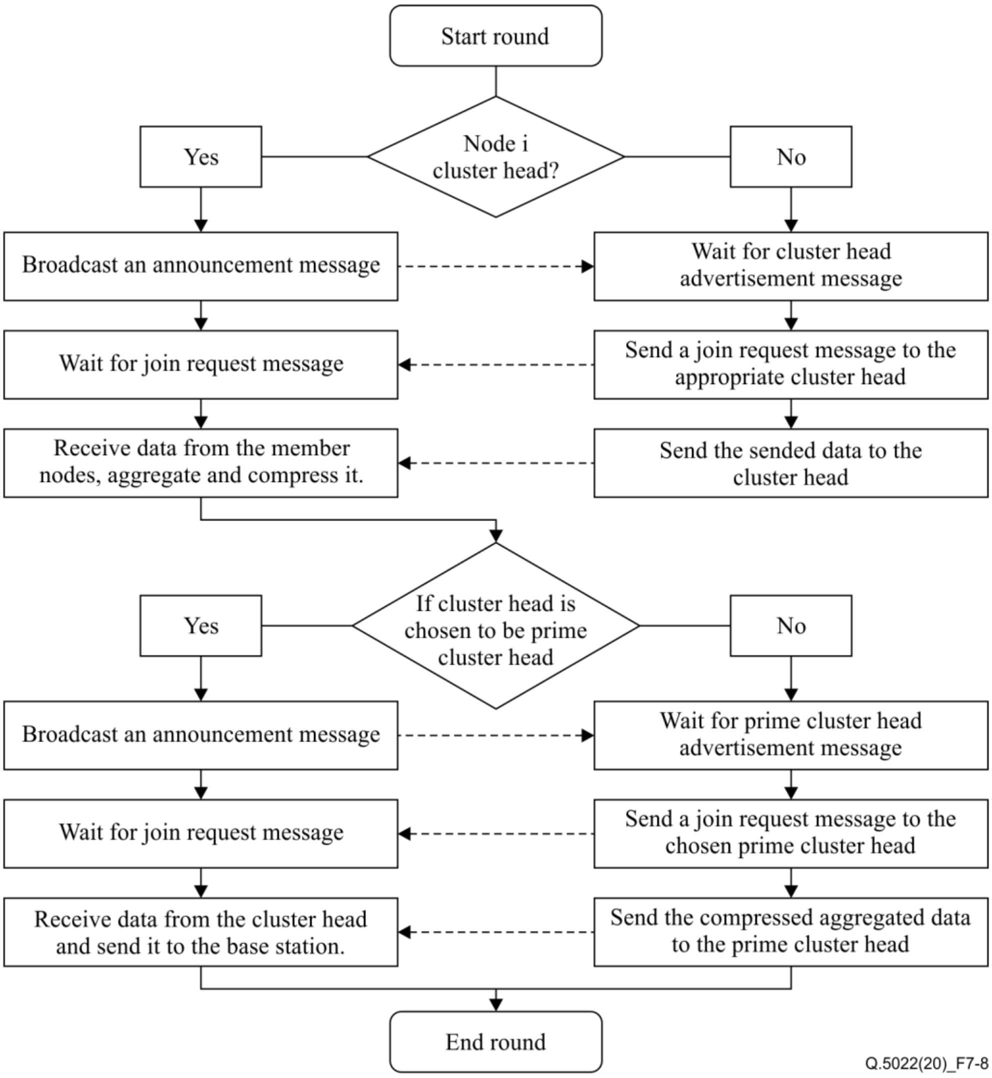

Figure 7-8 – Flow chart of MLHC operation

7.5 Cluster formation in failure mode

In failure mode, the vision is to maintain the cell operation without the BS. In order to achieve this vision an energy efficient multilevel clustering is employed. The cell is divided into clusters with a CH and CMs for each cluster and this is the first level of clustering. The network topology for this mode is illustrated in Figure 7-2. The communication inside clusters is out-band autonomous D2D type as CMs communicate with their CH using Wi-Fi direct.

In order to maintain the cell operation, CHs must be able to communicate with the neighbouring cells. Not all CHs can communicate directly with the neighbouring cells because of the distance and thus the second level clustering is performed.

A cluster is a group of several users with a CH that acts as the leader of the group. As the clusters are formed inside each cell, they are referred to as intra-cell clusters. All intra-cluster communications run over a WLAN in an unlicensed spectrum. In failure mode, cluster formation is achieved by users. The users switch to this mode only if they lose the control of BS due to failure or a catastrophic situation.

In order to maintain the cell operation, a multi-level clustering is applied in this mode. The main reason for applying clustering multiple-times is to enable all nodes to communicate with the boundary nodes. The boundary nodes are nodes that are located at the cell boundary and can communicate directly with nodes in the neighbouring cells.

The first level of clustering is formed based on the announced Wi-Fi direct specifications. Each Wi-Fi direct group represents a cluster and the group owner is the head of the cluster. Each CH receives the basic information of its CMs. This information contains the temporary mobile subscribe identity (M/S-TMSI), international mobile subscriber identity (IMSI) and the preferred payoff method. As a response, each CH that forms a schedule contains all member nodes in its cluster. The schedule contains the member node identification (CM-ID) allocated by the CH and other received data of the member nodes. CHs share their schedules and the downlink traffic with their CMs through broadcasting message.

To set up connections with the neighbouring cells, the first level cluster heads should find their way to communicate directly with nodes in the neighbouring cells. Not all CHs can communicate directly with the neighbouring cells because of the distance. CHs go on a discovery stage to discover which ones are able to reach and communicate with the neighbouring cells. All CHs broadcast a message and wait for a response from the neighbouring cells. CHs that are able to reach to the neighbouring cells announce themselves as a boundary CHs (BCHs or CHLN) and those are the CHs of the last clustering stage (N).

BCHs forms their clusters by broadcasting discovery messages for other first level CHs. CHs of the first level are able to receive the message of B-CHs, respond to the message and announce themselves as cluster heads of the clustering stage N-1 ($CH_{L(N-1)}$). The procedure of forming clustering levels goes on until all CH can reach to BCHs and thus to the neighbouring cells. Figures 7-9 to7-13 illustrate the formation of multi-level clustering in failure mode.

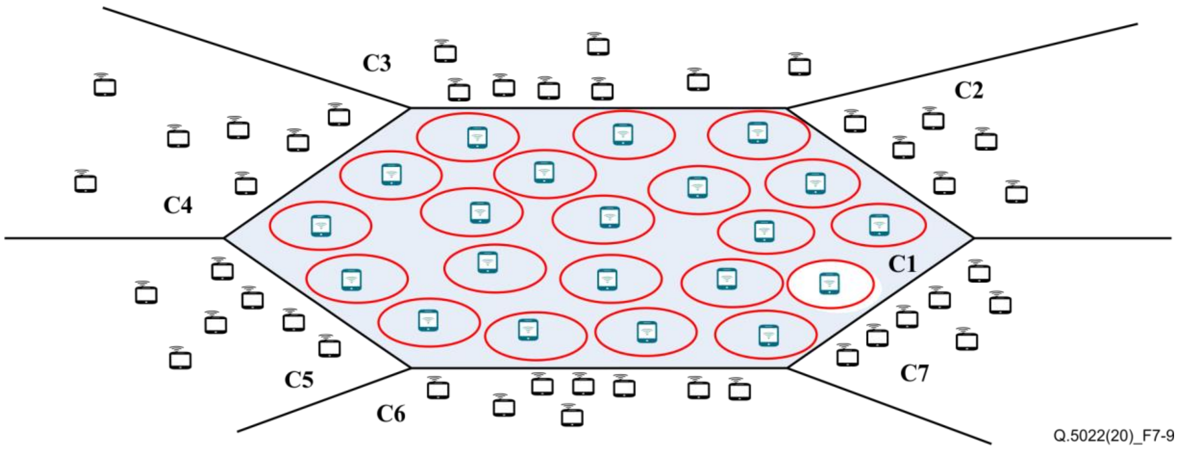

Figure 7-9 – First level cluster heads

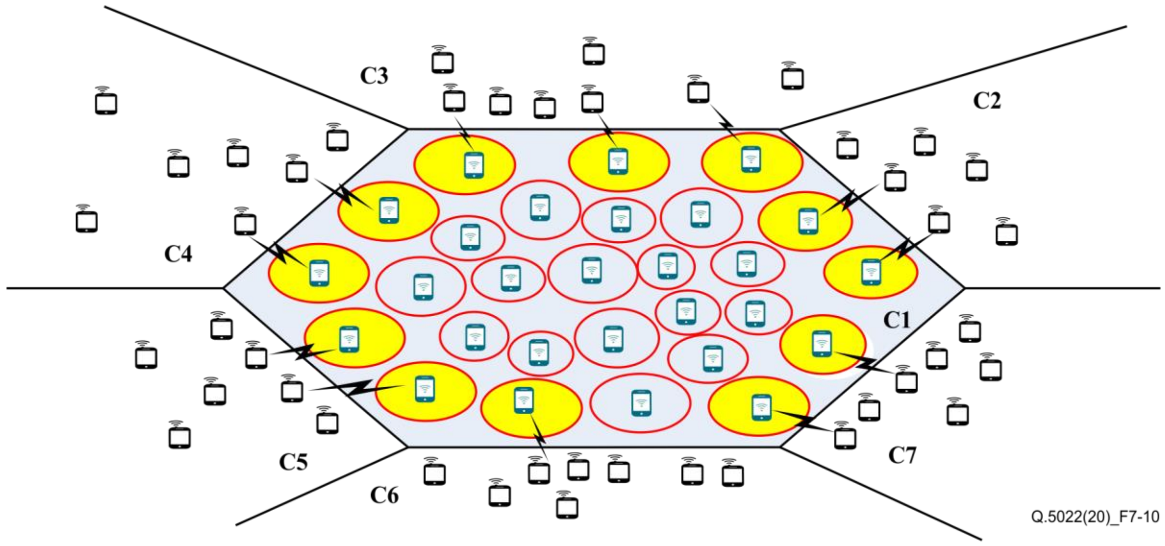

Figure 7-10 – Last level cluster heads (CH_{LN})

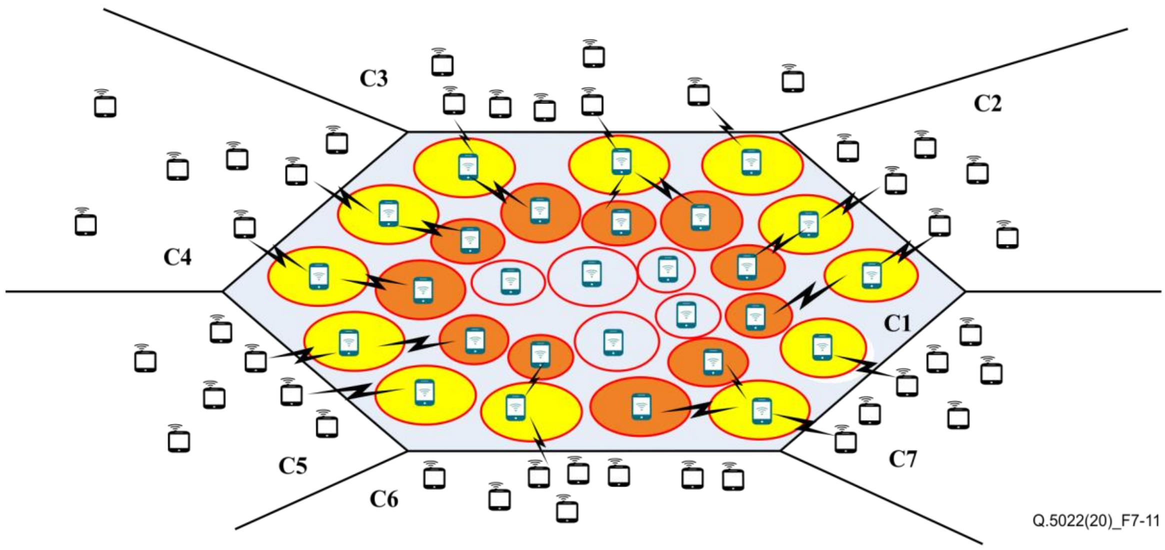

Figure 7-11 – (N-1) level cluster heads ($CH_{L(N-1)}$)

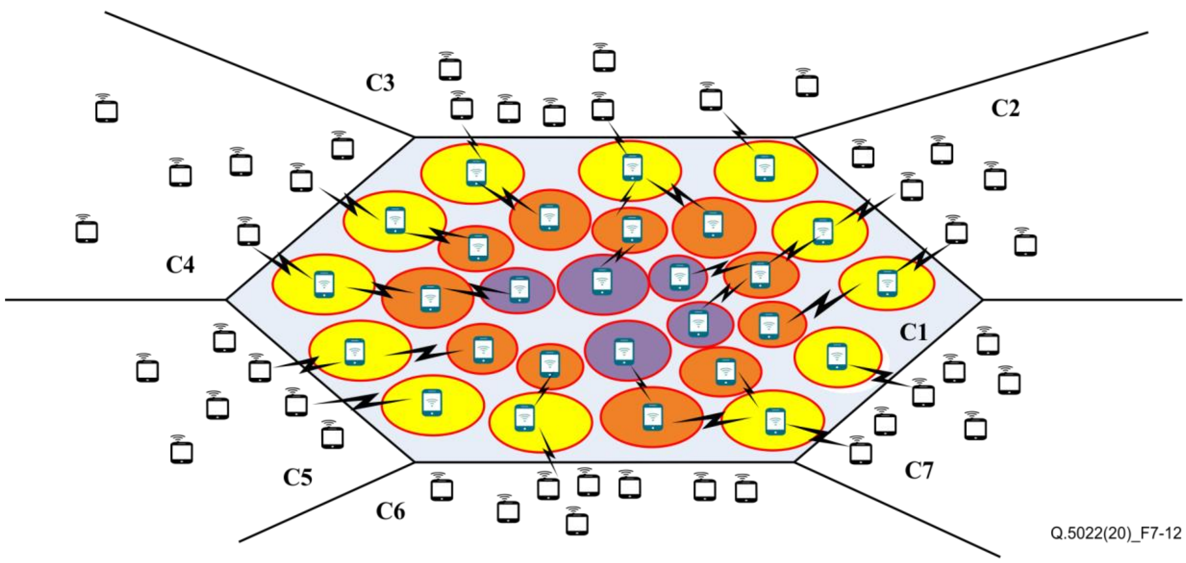

Figure 7-12 – Multi-level clusters

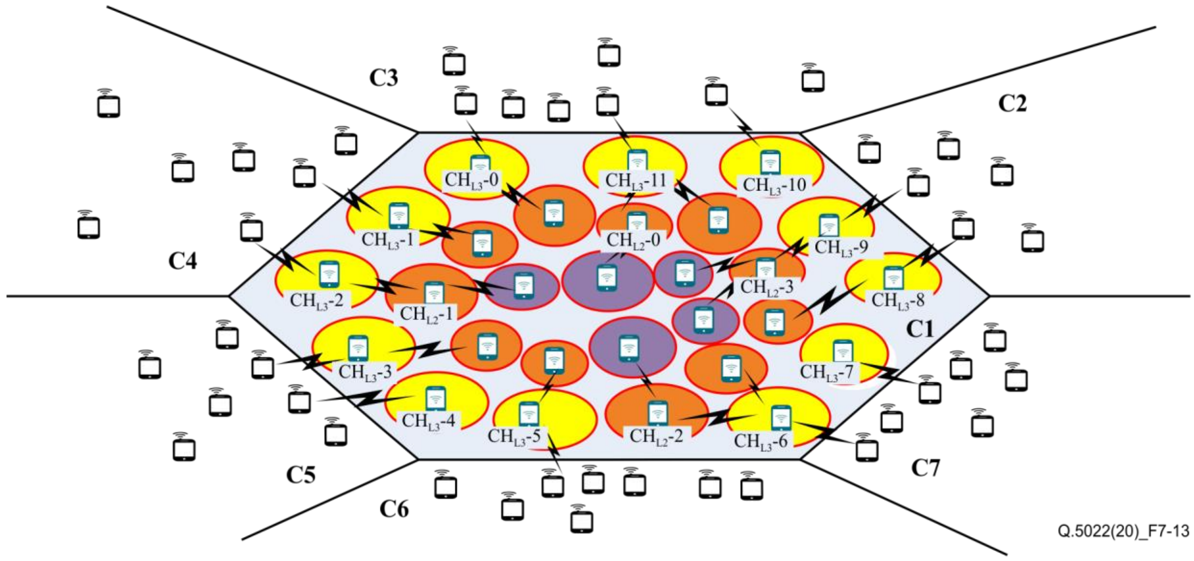

Figure 7-13 – Multi-level clusters with cluster head identifications

Appendix I

Use cases of D2D communications in IMT-2020 networks

(This appendix does not form an integral part of this Recommendation.)

Device-to-device (D2D) communication enables direct communication between proximate devices without relaying information to the base station (BS). Employing D2D communication in cellular networks achieves lots of benefits, including:

1) D2D communication provides an offloading way for the cellular network,

2) Increases spectrum efficiency,

3) Achieves higher throughput,

4) Reduces the traffic congestion, and

5) Achieves better cell coverage.

The proposed procedure is used to maintain the cell communication in case of the BS failure (due to either a technical problem or a catastrophic situation), thus the vision is to maintain the cell operation without the BS. If the cell users lose the control of the BS, they can switch to the D2D proposed procedure. The procedure employs the short range D2D communication as an alternative method to put the hole cell in communication with the neighbouring cells. Beside D2D communication, the cell nodes should be clustered more than once to enable reaching to the neighbouring cells. The main reason for applying clustering multi-times is to enable all nodes to communicate with the boundary nodes. The boundary nodes are nodes that are located at the cell boundary and can communicate directly with nodes in the neighbouring cells. Thus, in order to maintain the cell operation without BS, the proposed procedure employs multi-level cluster based D2D procedures. The idea behind multi-level clustering is to perform clustering between cluster heads of the first level and select some of them to be a second level cluster heads. Then the second level cluster heads select some of them to be a third level cluster heads and the procedure goes on until the final level cluster head.

D2D communication achieves many benefits for the cellular system and thus it must be embedded to the existing 4G and the future 5G cellular systems. Behind the benefits, D2D communication can also be used to solve some problems associated with the cellular system; one of them is the BS failure. Employing multi-level clustering with D2D communication is an efficient way to maintain the inter-cell communication without BS. Multi-level clustering gives all nodes inside the cell communication paths to neighbouring cells and thus can perform all required communication processes.

In case of catastrophic situation, the proposed procedure is an efficient way to preserve the cell communication. The worst case is the failure of the BS and those of all neighbouring cells, in this situation the proposed procedure does not help. The best case for employing the proposed procedure is the BS failure due to a technical problem or a regional catastrophic situation with all BSs of neighbouring cells in operation.

Appendix II

Gap analysis about D2D communications in related SDOs

(This appendix does not form an integral part of this Recommendation.)

No.	SDOs	Title	Status	Analysis results
1	ITU-R M.2083	Framework and overall objectives of the future development of IMT for 2020 and beyond, ‖ Sep. 2015	Published, in force	This Recommendation states that by 2020, the first commercial release of fifth generation cellular system (5G) will be launched according to the road map of the International Telecommunication Union (ITU) road map for the International Mobile Telecommunications-2020 system (IMT-2020).
2	ITU-R M.2410-0	Minimum requirements related to technical performance for IMT-2020 radio interface(s), ‖ Nov. 2017	Published, in force	New features and services that cover the needs of market segments and verticals. Far from the traditional services provided by the current cellular systems, 5G will introduce new types of services and applications with the developed new radio (NR)
3	3GPP TS 22.261,	Service requirements for next generation new services and markets; Stage 1, ‖ Release 15, August 2016	Published, in force	The 3rd Generation Partnership Project (3GPP) in this release show the mean services and roadmap for the first 5G release.
4	3GPP TS 27.502	Procedures for the 5G System, ‖ 2017	Published, in force	3GPP launched the Study on New Services and Markets Technology Enablers project (SMARTER), in 2015, to define and develop high level use cases and services of 5G system that meet the market demands. Moreover, SMARTER is expected to define the main features and requirements for each use case scenario. The work of SMARTER project is included in release 14 and 15. The 3GPP roadmap of 5G systems includes four main releases including release 13, 14, 15 and release 16. Each release contains different phases that are merged at the final stage of each release. Release 14 has been frozen by the end of the last year, while release 15 is going to be frozen by the end of this year completing the first phase of 5G.
5	ISO/CD 17515-2	Intelligent transport systems – Communications access for land mobiles (CALM) – Evolved universal terrestrial radio access network (E-UTRAN) – Part 2: Device to device communications (D2D)	Under development	Device to device communications (D2D)

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Printed in Switzerland
Geneva, 2020