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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

ITU-T L.1700 – Setting up a low-cost sustainable telecommunication network for rural communications in developing countries using cellular network with capacity transfer

ITU-T L-series Recommendations – Supplement 30

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Supplement 30 to ITU-T L-series Recommendations

ITU-T L.1700 – Setting up a low-cost sustainable telecommunication network for rural communications in developing countries using cellular network with capacity transfer

Summary

Supplement 30 to ITU-T L-series Recommendations provides a description of the cellular network with capacity transfer system that has been developed taking into account specific requirements for communications in rural and remote areas with special attention to low expenditure on all components of the system, focusing on low operating cost, low power consumption, very effective coverage zones and low requirements for maintenance of the system. The key benefit is achieved by relaying of the cellular air interface in a frequency band other than standard cellular, which allows the substitution of a significant part of the base station (BS) and microwave link (ML) or optical fibre links interconnecting them.

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Introduction

Existing mobile network systems are primarily defined for urban areas where the necessary support infrastructure (adequate power, building or shelter, accessibility, skilled manpower to operate etc.) for setting up a telecommunication network is assumed to be in place. Hence current systems do not meet rural specific requirements and cannot be mass deployed. A cellular network with capacity transfer is a very attractive mobile network system that can be used in rural areas and provides a very low capital and operating cost, a very low power consumption, a very effective coverage of sparsely populated and scattered population clusters, a very quick deployment of the system to give "last-mile" service for customers with high economic efficiency. Fundamentally, the key benefit is achieved by relaying of the cellular air interface in a frequency band other than standard cellular, which allows the substitution of significant part of the base station (BS) and microwave link (ML) or optical fibre links interconnecting them.

Supplement 30 to ITU-T L-series Recommendations

ITU-T L.1700 – Setting up a low-cost sustainable telecommunication network for rural communications in developing countries using cellular network with capacity transfer

1 Scope

This Supplement provides a system description of the cellular network with capacity transfer, functional description, system performance and capacity, coverage areas and provided advantages in comparison with standard cellular network in economic, power consumption, capital and operating cost, maintenance, rapid deployment and quality of service.

2 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

BS	Base Station
BS-R	transfer unit
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CTR	Capacity Transfer Repeater
DRM+	Digital audio broadcasting system
DU	Digital Unit
EDGE	Enhanced Data rates for GSM Evolution
ERP	Effective Radiated Power
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HSPA	High-Speed Packet Access
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution-Advanced
ML	Microwave Link
MS	Mobile Station (subscriber terminal)
OFC	Optical Fibre Cable
OPEX	Operating Expense
PS	Power Supply
QoS	Quality of Service
RAN	Radio Access Network
RC	Radio frequency Converter
RF	Radio Frequency
RRH	Remote Radio Head
SDR	Software-Defined Radio

TRX Transceiver

UMTS Universal Mobile Telecommunication System

X CTR transceiver

3 System description

3.1 General overview

The cellular network with capacity transfer principle is illustrated in Figure 1. In the traditional cellular network topology, the capacity is statically distributed among BSs of the radio access network (RAN). The cellular network with capacity transfer is built around a central BS where radio resource is concentrated and distributed to light repeater-like service stations. That principle allows the achievement of high efficiency and flexibility in the cellular network.

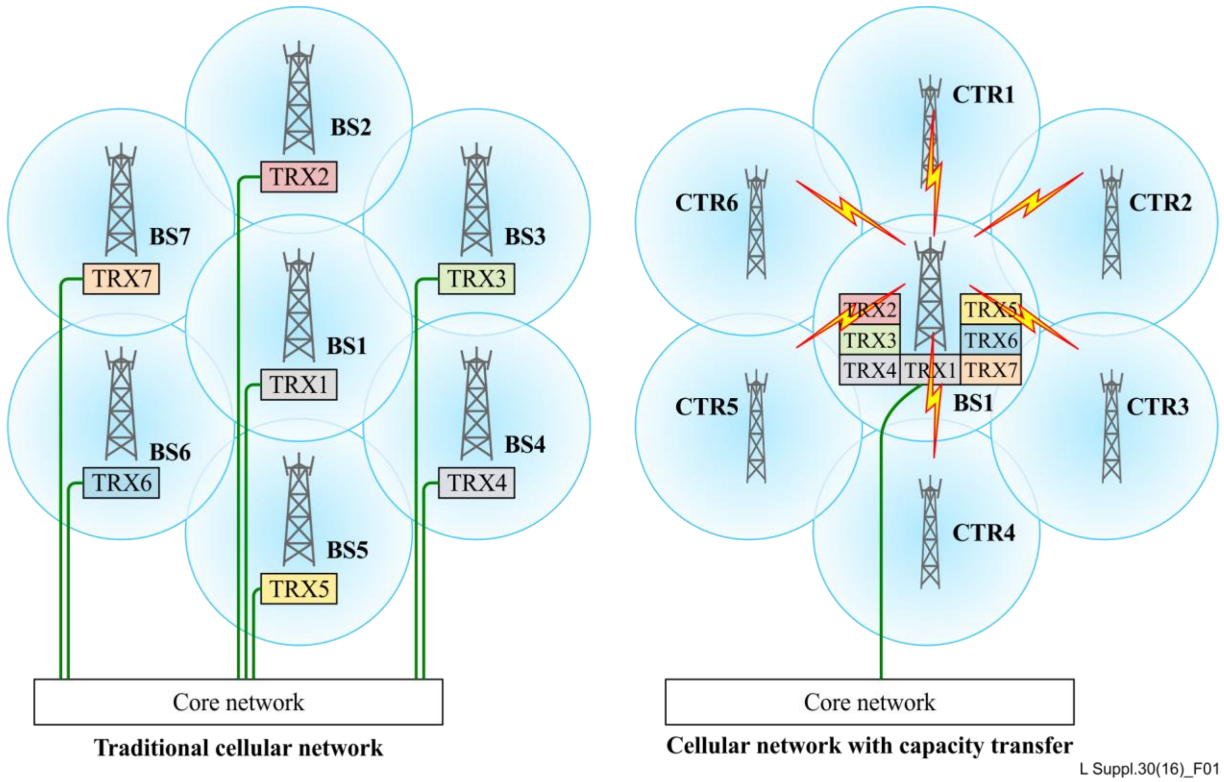

Figure 1 – Cellular network with capacity transfer principle

The cellular network with capacity transfer principles are implemented in the capacity transfer repeater (CTR).

CTRs are bidirectional amplifiers that perform reception, selection (filtering) and amplification of radio signals, as well as the conversion of their carrier frequency from the cellular band to a different frequency range (usually higher) and vice versa. Variable gain allows the establishment of the necessary zone of radio coverage. CTR transfers radio signals from the base station (BS) of a cellular network to the mobile station (MS) subscriber terminal and in the reverse direction.

The solution allows the expansion of the coverage zone of the BS with a simultaneous increase of the overall channel capacity of the cellular network with the relay of the whole sector.

As a result, the number of required BSs and corresponding microwave links (MLs) in a cellular network is significantly reduced, as well as the total cost of the system.

The expanded coverage zone consists of relayed sectors of a single BS with no intercell handovers between service areas of the CTRs connected to the same BS. In this case, only intra-cell inter-sector handovers take place, which, depending on the standard and the equipment, could be handled by the BS itself. This fact enables significant reductions of signalling overhead and call drops, which in turn improve quality of service (QoS), especially in complex coverage areas.

Usage of the frequency bands outside the cellular frequency band by CTRs for relaying dramatically reduces the impact of intersystem interference in comparison with common repeaters. There are a number of options for relay channel arrangement.

- Out of the cellular bands:
  - ML bands;
  - whitespaces;
  - licensed and unlicensed bands.
- In the cellular bands:
  - regionally unused cellular bands and sub-bands;
  - locally unused cellular spectrum;
  - reformed bands and sub-bands.

The low power consumption of CTRs allows usage of alternative sources of power (solar panels, wind power) that greatly facilitates the provision of radio coverage in sparsely populated and remote areas. See Figure 2.

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- Shelters or climate enclosures are needed.
- Large load capacity masts are required.
- An air conditioning system is needed.
- Microware or optical fibre transport is required.
- High power consumption of the site.
- Significant capital expenditures

a) Typical site of a base station

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- Compact size monoblock.
- Block can be mounted on top of the mast.
- Reduced lease expences.
- Light design masts can be used
- Energy consumption of the site reduced by 3-5 times
- Reduces capital and operational costs.
- Built-in power supply.

b) Typical capacity transfer repeater site

Figure 2

The cellular network with capacity transfer assumes changes in cellular network topology. However, it does not require changes to cellular communication standards. It provides a number of considerable advantages to traditional cellular networks:

- One CTR, consuming less than 180 W per sector for the global system for mobile communications (GSM) and 60 W per sector for universal mobile telecommunication system/long-term evolution (UMTS/LTE), substitutes for BS, ML or optical fibre and power supply (PS) that can consume 1.5-3 kW;
- Reduction of operating expense (OPEX) by more than two to three times, while preserving an equivalent coverage and capacity;
- Cooperative service for two to three different operators (RAN sharing) with capital expenditure (CAPEX) and OPEX reduction by two to four times per site for each operator;

- Exclusion of inter-cell handovers between CTR sites connected to one BS;
- Reduction of relay channel bandwidth compared to standard ML by 1.3 to six times depending on cellular standard and conditions;
- RAN capacity redistribution to handle local areas overloads;
- Variable topology of cellular network achieving call drops reduction, improved QoS, indoor and underground coverage without handovers to above-ground network;
- Compatibility with any vendor BSs;
- Compatibility with any BS software versions, no need for software updates;
- Invariance to cellular standards and their versions.

Principles of cellular network with capacity transfer are described in [b-RU 2279764 C1], [b-US 8,289,888 B2], [b-EP 1890399 B1], [b-CN 101006665 B], [b-India 258620] and [b-UA 91347 C2].

3.2 Functional description

The main functional purpose of the CTR is to transfer capacity of one or more sectors of the BS to remote areas. In this case, the entire infrastructure needed for BS functioning is placed at the BS site.

Figure 3 shows an example of the highway coverage by GSM BSs. Each BS includes two transceivers (TRXs), a digital unit (DU) and a PS. Base station BS1 is connected to the core network by an optical fibre cable (OFC).

BSs are interconnected by MLs. All BSs at the sites are supposed to have a similar configuration – each one is installed in the container close to the tower, on the top of which receiving and transmitting GSM antennas are installed, as well as an ML and its antenna equipment.

Container BSs site design requires significant CAPEX. TRX cable connections of the BS installed in the container with the antennas make a significant attenuation of signals during transmission and reception to compensate, which is necessary to increase the power of the BS transmitter. Power consumption of the site, taking into account the air conditioner installed in the shelter, is 3-5 kW.

The use of distributed BSs, where radio frequency (RF) remote radio head (RRH) units are placed next to the antennas and baseband DUs are installed in a climatic cabinet, helps reduce the power consumption of the sites down to 1-2 kW.

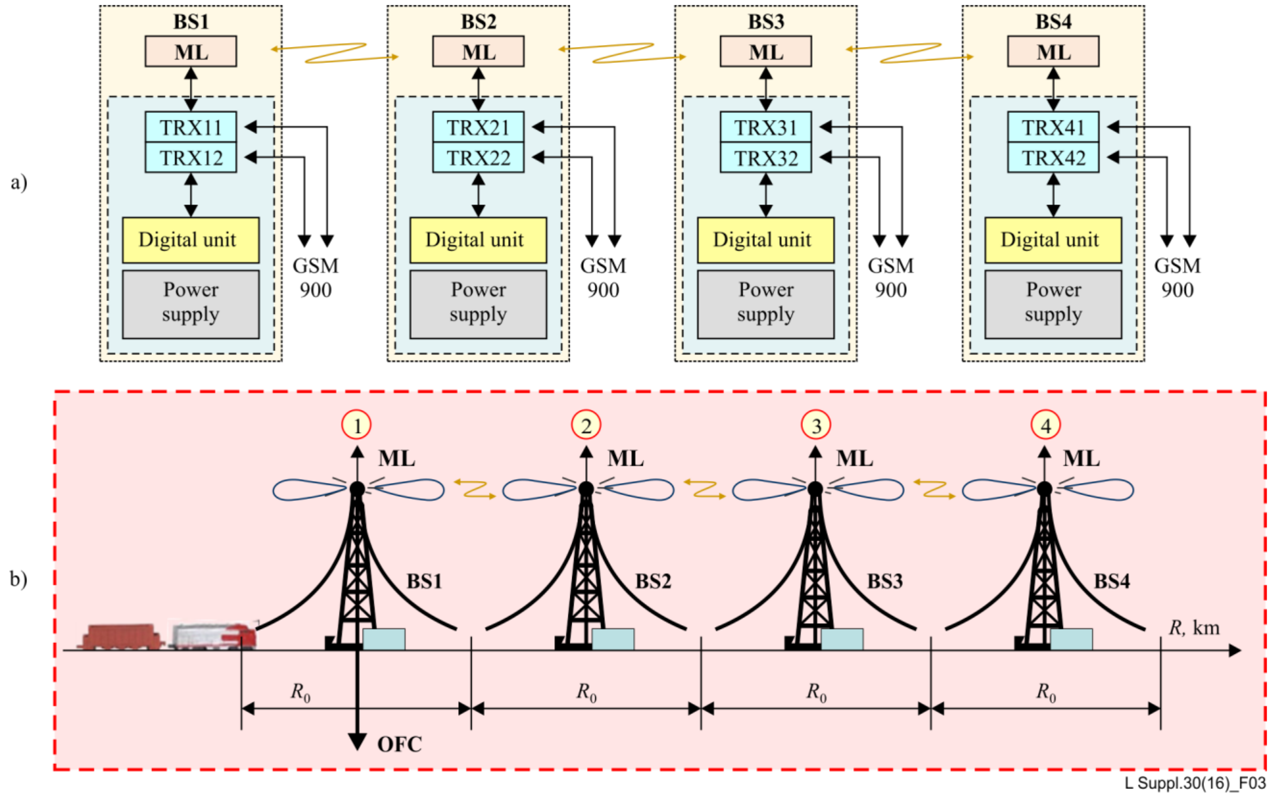

Figure 3 – Cellular network with standard BSs

Figure 4 shows the scheme of coverage of the same route using capacity transfer repeaters (CTR1, CTR2, CTR3). A BS is complemented by a transfer unit (BS-R) that consists of six transceivers of GSM signals operating at relay frequencies (f_r) beyond the standard GSM frequency bands (relay channel), commonly allocated to transfer data (e.g., for ML).

CTR1 consisting of six transceivers is placed on the top of the next in a chain of site towers (2):

– two transceivers (X1, X2) of the CTR1 transfer GSM signal from f_r frequencies to the standard GSM 900 or GSM 1800 frequency band and form a GSM coverage zone equivalent to the base station BS2 (Figure3-b) on both sides of the tower;

– four transceivers (X3 to X6) of the CTR1 transfer GSM signals from one set of f_r frequency carriers to the other set of f_r carriers, continuing the chain of transfer.

On tower (3) CTR2 consisting of four transceivers is installed:

– two transceivers (X1, X2) of the CTR2 transfer GSM signal from f_r frequencies to the standard GSM 900 or GSM 1800 frequency band and form a GSM coverage zone equivalent to the base station BS3 (Figure 3-b) on both sides of tower (3);

– two transceivers (X3, X4) of the CTR2 transfer GSM signals from one set of f_r frequency carriers to the other set of f_r carriers, continuing the chain of transfer.

On tower (4) the simplified repeater – CTR3, which ends the transfer chain, is installed.

Depending on the required network capacity, more or fewer relay channels can be used in the BS and CTRs and more or fewer CTRs can be used in the transfer chain.

In the considered scheme, a BS is installed on the site where OFC and a PS are available. In this case, it is possible to form another similar transfer chain of the GSM signal to the "left" of the BS. The total length of the route with one BS and six CTRs with cell size R_0 between 6 and 10 km will be between 42 and 60 km.

In the scheme considered in Figure 4, the network capacity is equal to the capacity of a standard GSM network.

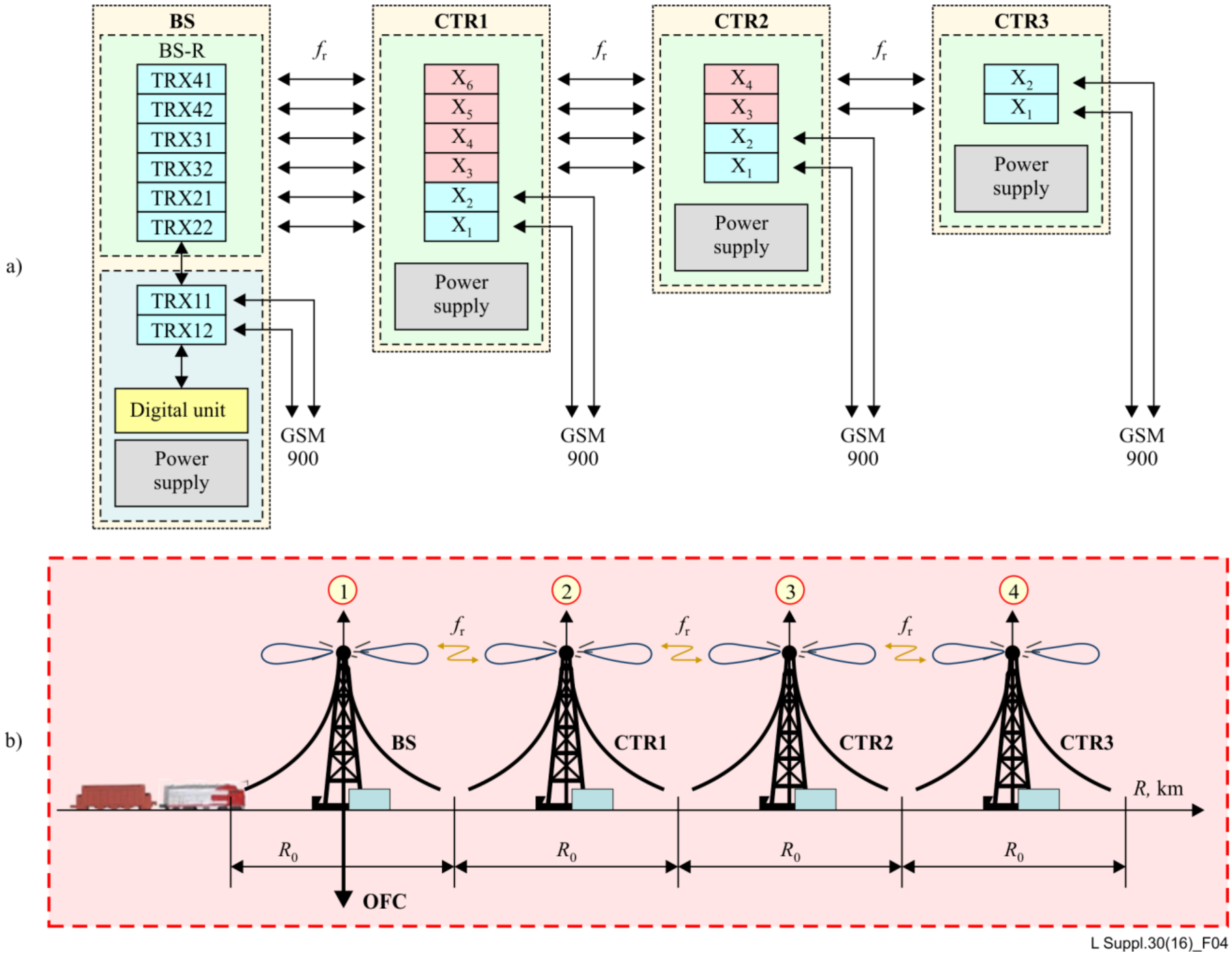

Figure 4 – Cellular network with capacity transfer

Introduction of the GSM air interface to transfer data in frequency bands other than standard GSM 900/1 800/1 900 MHz bands allows the elimination of the use of a ML to interconnect BSs. This is fundamentally new in the cellular network with capacity transfer.

It should be noted that the power of transmitters of BS-R transfer units at the BSs and transmitters in the relay channels of CTRs is 0.2-0.5 W, since the data is transferred from tower to tower using directional antennas with a gain of 15-30 dB. The additional power required from the PS for the BS (for BS-R) will be 50-60 W.

The considered scheme of cellular network with capacity transfer allows six BSs and six MLs to be replaced by six CTRs. In addition, the replacement of standard BSs by CTRs allows the use of cheaper towers. Power consumption of the CTR site in the considered scheme with the power of two transmitters of 20 W effective radiated power (ERP), is 150-300 W, which allows the use of solar panels or other alternative energy supply sources for CTRs.

Figure 5 shows a scheme of one of the implementation options of a cellular network with capacity transfer that uses a standard BS of any vendor with additional TRXs, operating at GSM 900 MHz or GSM 1 800 MHz frequencies. Transfer of GSM signals to relay frequencies (f_r) is performed by the radio frequency converter (RC). The use of a single RC in the considered scheme allows the use of BSs of any vendor in the standard configuration.

The optimal implementation option of a cellular network with capacity transfer is shown in the scheme in Figure 6, where within the BS a single unit of TRXs is included, which transmits GSM signals at f_r frequencies with the transmission power of each TRX of about 0.2-0.5 W. Considering the use of directional antennas with a gain of 15-30 dB, stable communications in the 3-6 GHz band relay channels can be ensured for cells of diameter 6-10 km.

Examples of a cellular network with capacity transfer implementation for coverage of settlements are described in clause 4.4 .

Single-span repeaters (labelled CTR3) can be used to provide coverage in buildings. A linear relay chain can also be used to provide communications in tunnels.

A cellular network with capacity transfer can be applied to global system for mobile communication/general packet radio service/enhanced data rates for GSM evolution (GSM/GPRS/EDGE), universal mobile telecommunication system/long-term evolution/high-speed packet access (UMTS/HSPA), code division multiple access (CDMA), long-term evolution/long-term evolution-advanced (LTE/LTE-A) standards of cellular communications and can be used in broadband wireless access systems, digital television, audio broadcasting systems (DRM+) and requires no modification when software on the BS is upgraded.

Figure 7 shows a scheme of a cellular network with capacity transfer of UMTS or LTE standards. The system supports both standards simultaneously.

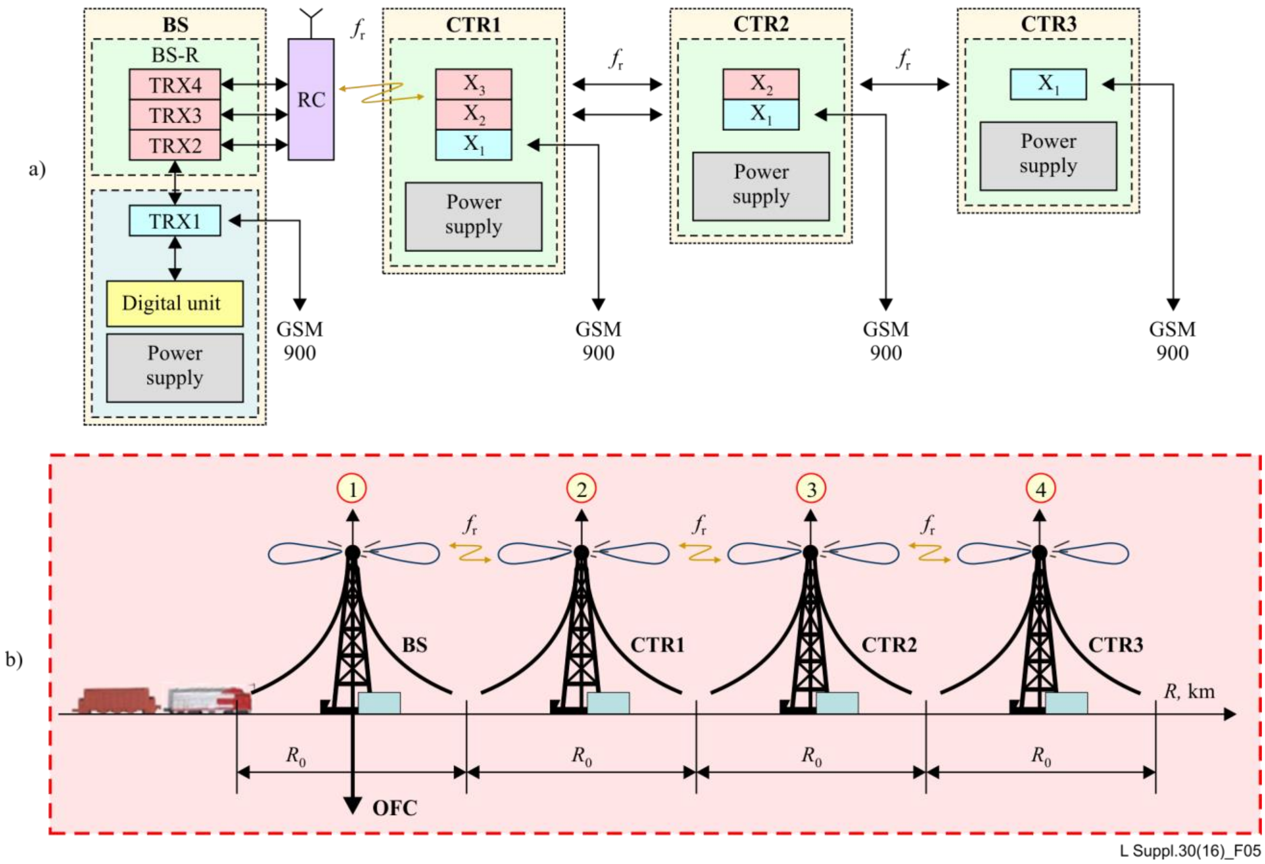

Figure 5 – Cellular network with capacity transfer with a standard BS and the frequency converter

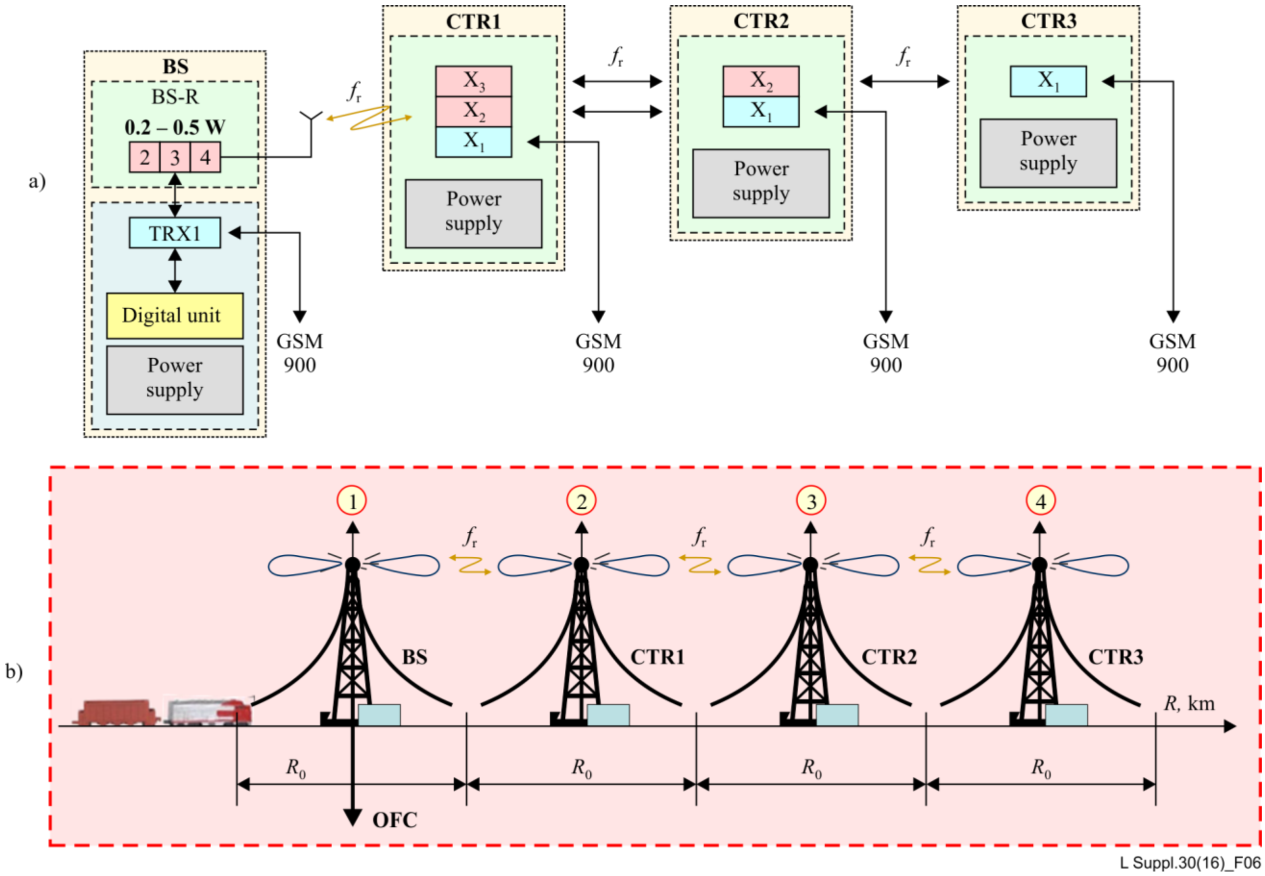

Figure 6 – Cellular network with capacity transfer, an option with a transfer unit at BS

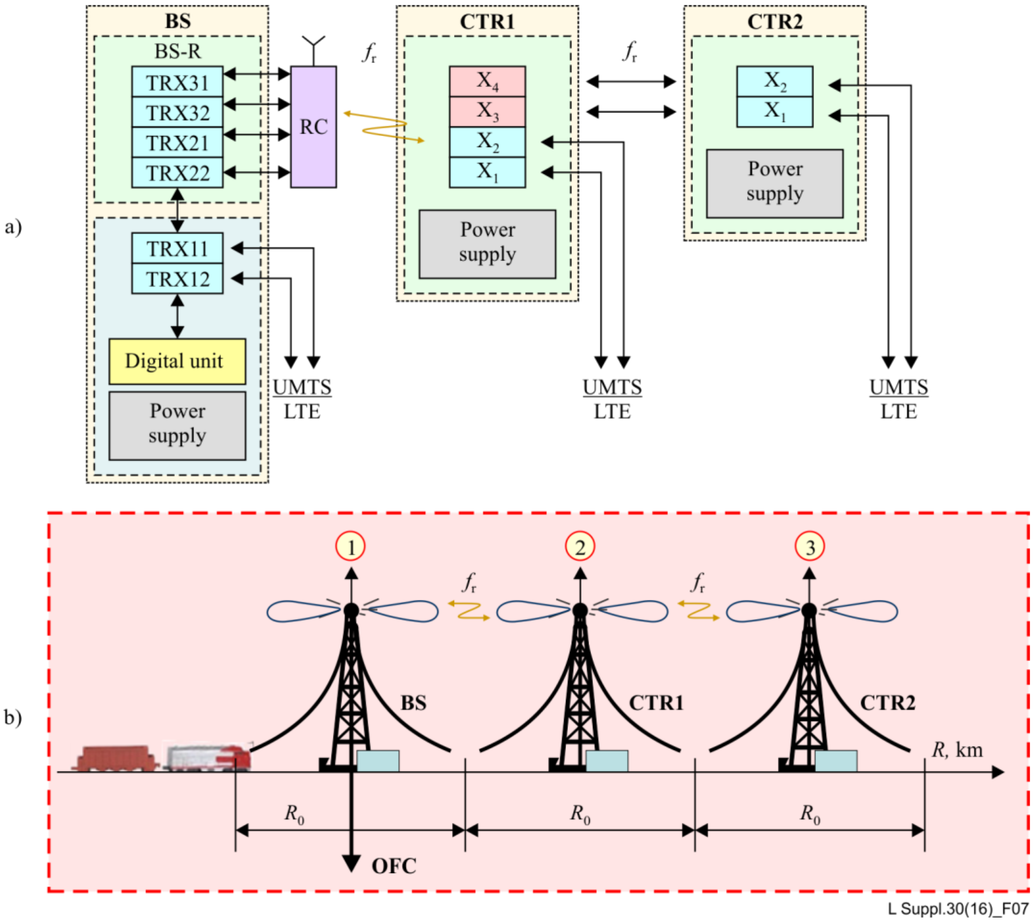

Figure 7 – Cellular network with capacity transfer of universal mobile telecommunication system or long-term evolution standards

3.3 Developed equipment performance and capacity

The developed equipment supports radio access technologies: GSM/GPRS/EDGE, UMTS/HSPA and LTE/LTE-A.

Software-defined radio (SDR) and modular principles in the equipment allow its easy adaptation to changing requirements and new standards of cellular communications.

Number of consecutive spans: up to three for GSM and UMTS; up to two for LTE.

GSM CTR capacity: the equipment is able to transfer up to six GSM carriers from BS through a single relay chain.

UMTS or LTE/LTE-A CTR capacity: the equipment is able to transfer up to four UMTS/LTE carriers, depending on carrier bandwidth, from BS through a single relay chain.

3.4 General specification of GSM CTR equipment

See Table 1.

Table 1 – General specification of GSM CTR equipment

Parameter	BS-R	CTR type 1	CTR type 2
GSM Channels operating frequencies range, MHz DL: UL:	 918-960 873-915	 918-960 873-915	 918-960 873-915
GSM Channels spacing, kHz	200	200	200
Relay Channels operating frequencies range, MHz (other frequency options are possible)	6 185 to 6 425 5 925 to 6 165	6 185 to 6 425 5 925 to 6 165	6 185 to 6 425 5 925 to 6 165
Number of GSM Carriers	1 to 6	1 to 2	1 to 2
Number of Relay Channels from BS side	–	1 to 6	1 to 2
Number of Relay Channels from MS side	1 to 6	1 to 4	–
GSM Channels receivers Noise figure, dB	≤8	≤3	≤3
Relay Channels receivers Noise figure, dB	≤5	≤5	≤5
Relay Channels transmitters per carrier power, dBm	≤27	≤27	≤27
GSM Channels transmitters per carrier power (GMSK), dBm	≥−10	≥40	≥40
Signal propagation delay per unit, µs	≤5.5	≤5.5	≤5.5
Power supply, V	–48 (DC)	110 to 230 (AC)	110 to 230 (AC)
Backup power supply, V DC	–	12 to 36	12 to 36
Power consumption, W	≤100	≤300	≤250
Local control via a standard Ethernet port	Yes	Yes	Yes
Remote control via a GSM-modem	Yes	Yes	Yes
RF inputs/outputs nominal impedance, Ω	50	50	50
Environment protection	IP 65	IP 65	IP 65
Operating temperature range, ºC	−40 to +55	−40 to +55	−40 to +55
Storage temperature range, ºC	−50 to +70	−50 to +70	−50 to +70
GSM antenna connectors	DIN 7/16	DIN 7/16	DIN 7/16
Relay antenna connectors	N-type	N-type	N-type
Dimensions, mm	430 × 406 × 318	594 × 400 × 318	594 × 400 × 318

3.5 General specification of UMTS or LTE CTR equipment

See Tables 2 and 3.

Table 2 – General specification of UMTS or LTE CTR equipment

Parameter	BS-R	CTR type 1	CTR type 2
UMTS Channel operating frequencies range, MHz DL: UL:	2 110-2 170 1 920-1 980	2 110-2 170 1 920-1980	2 110-2 170 1 920-1 980
LTE Channel operating frequencies range, MHz DL: UL:	1 805-1 880 1 710-1 785	1 805-1 880 1 710-1 785	1 805-1 880 1 710-1 785
Relay Channels operating frequencies range, MHz (other frequency options are possible)	6 770 to 7100 6 430 to 6760	6 770 to 7 100 6 430 to 6 760	6 770 to 7 100 6 430 to 6 760
LTE Channels spacing, MHz	5, 10, 20	5, 10, 20	5, 10, 20
Max Sum Bandwidth, MHz	20	20	20
UMTS and LTE Channels receivers Noise figure, dB	≤3	≤3	≤3
UMTS and LTE Channels TX Power, dBm	–60 to −30	27 to 40 (1dB step)	27 to 40 (1dB step)
Relay Channel Noise Figure, dB	5.5	5.5	5.5
Power supply, V	–48 (DC)	110…230 (AC)	110…230 (AC)
Backup power supply, V DC	–	12…36	12…36
Power consumption per sector, W	≤60	≤60	≤60
Local control via a standard Ethernet port	Yes	Yes	Yes
Remote control via a LTE/UMTS/GSM-modem	Yes	Yes	Yes
Network Wireless Interface	802.11n 2.4 GHz (150 Mbit/s)	802.11n 2.4 GHz (150 Mbit/s)	802.11n 2.4 GHz (150 Mbit/s)
RF inputs/outputs nominal impedance, Ω	50	50	50
Environment protection	IP 65 (IP 67 optional)	IP 65 (IP 67 optional)	IP 65 (IP 67 optional)
Operating temperature range, ºC	–40 to +55	–40 to +55	–40 to +55
Storage temperature range, ºC	–50 to +70	–50 to +70	–50 to +70
Dimensions, mm	300 × 300 × 200	300 × 300 × 200	300 × 300 × 200

Table 3 – Capacity transfer repeater configuration options

	Sector 1	Sector 2	Sector 3
Option 1	UMTS	UMTS	UMTS
Option 2	UMTS	UMTS	LTE
Option 3	UMTS	LTE	LTE
Option 4	LTE	LTE	LTE

4 Best practice

4.1 Capacity transfer repeater implementation to provide highways and railways network coverage

One of the typical tasks during the construction of cellular networks is to provide coverage along highways, roads and railways. Usually, it is achieved by BS installation on new or existing poles along the route. Roads are linearly extended objects and a cellular network along these objects usually is planned in a chain.

Figure 8 shows a scheme of a typical road segment where radio coverage is provided with CTR (linear topology is explained in clause 3.2).

There can be several relay chains of CTRs connected to one BS. For example, two relay chains can be used along roads (to provide coverage in opposite directions from the BS, see Figure 8). Three or four relay chains can be used when the BS is installed near forks and intersections.

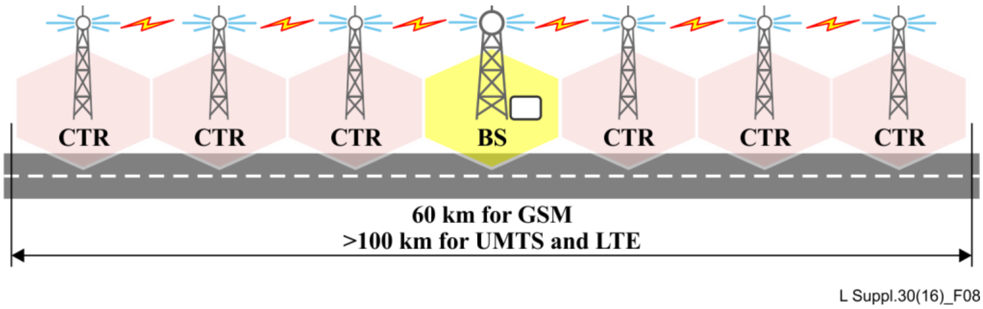

Figure 8 – Cellular network with capacity transfer for coverage of a road segment

Depending on the standards for radio interface limitations, the length of the road segment covered by two CTRs chains in opposite directions can be up to 60 km for GSM and more than 100 km for UMTS and LTE.

4.2 Capacity transfer repeater implementation to provide coverage in settlements situated up to 30 km away from main routes

To cover a remote rural area located up to 30 km away (in the GSM case) and more than 50 km away (in the UMTS and LTE cases) from the main road, an additional network segment with CTRs may be deployed (three additional sites with CTR + equipment of the existing on-route BS site with additional TRXs and RC). That replaces the installation of three BSs with infrastructure and transport channels. See Figure 9.

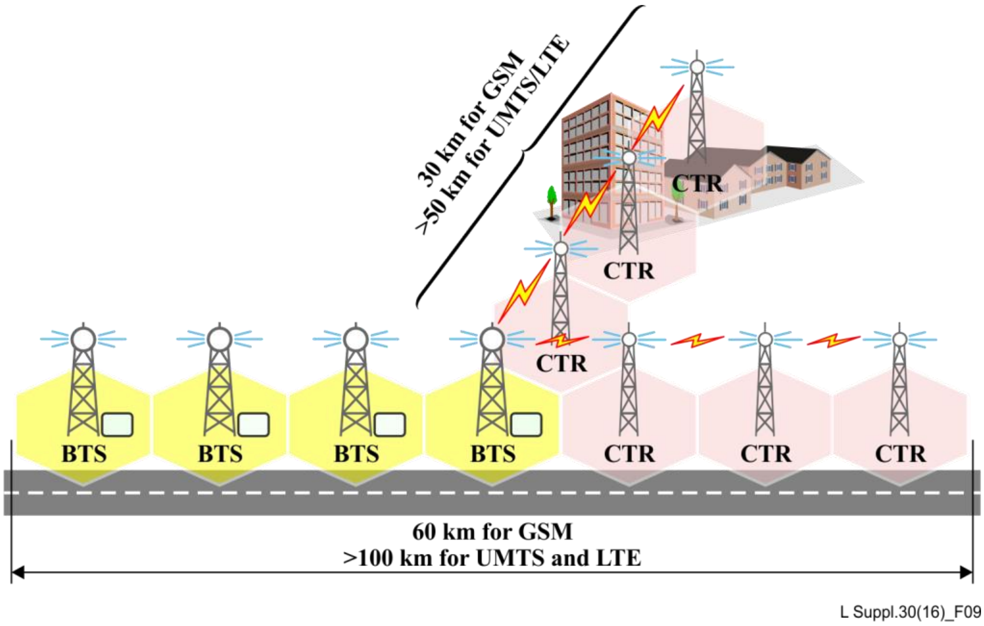

Figure 9 – Cellular network with capacity transfer for cover of settlements situated away from the main road

4.3 Capacity transfer repeater implementation in sparsely populated areas

In sparsely populated areas, cellular networks have patchy coverage, i.e., services are available in local concentrations of population in cities and towns.

Figure 10 shows an example of a communication scheme with patchy coverage with CTR.

In this case, in addition to a town cellular network consisting of five BSs and transport infrastructure, two BSs and transfer units BS-R1 and BS-R2 for two relay chains are placed on two sites, BS A and BS B. The capacity transfer repeaters themselves CTR1/1, CTR1/2, CTR1/3 and CTR2/1 are located in remote settlements. Network frequency planning is performed by standard methods. Thus, the capacity of additional BSs is moved via relay chains to the settlements. In a traditional cellular network, the installation of four BSs with complete infrastructure and transport channels would be required at these points. Taking into account that, in this case, the BS sector capacity is fully relayed, CTRs can be considered as ordinary BSs with corresponding parameters while network RF planning.

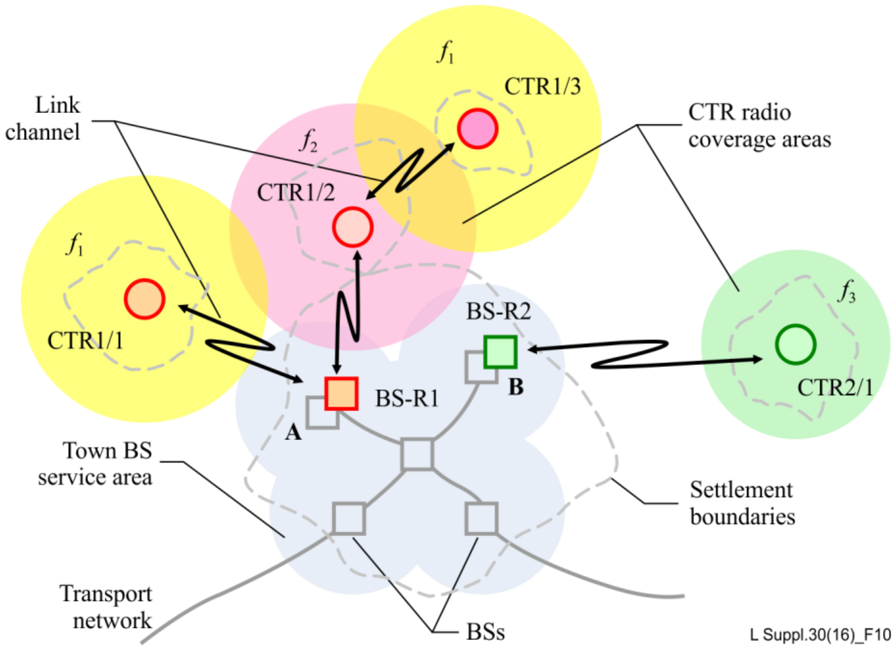

Figure 10 – Cellular network with capacity transfer for patchy coverage

4.4 Capacity transfer repeater implementation in towns and settlements

In small cities and towns, CTRs can be used to replace standard BSs in the cellular network while keeping the capacity and coverage, considerably lowering the power requirement of the network in a town, see Figure 11.

For example, Figure 11-a shows the configuration of a GSM cellular network with capacity transfer for settlements. The scheme uses a single-span transfer of GSM signal, allowing eight BSs to be replaced by CTRs. With a cell diameter of 6 km, the diameter of the coverage zone can reach about 18 km. The required network capacity can be provided with the necessary number of TRXs at the BS and the corresponding number of relay channels.

Figure 11-b shows a scheme of a cellular network with capacity transfer for settlements replacing 24 BSs. Given cell sizes of 6 km, the diameter of the coverage zone will be about 30 km.

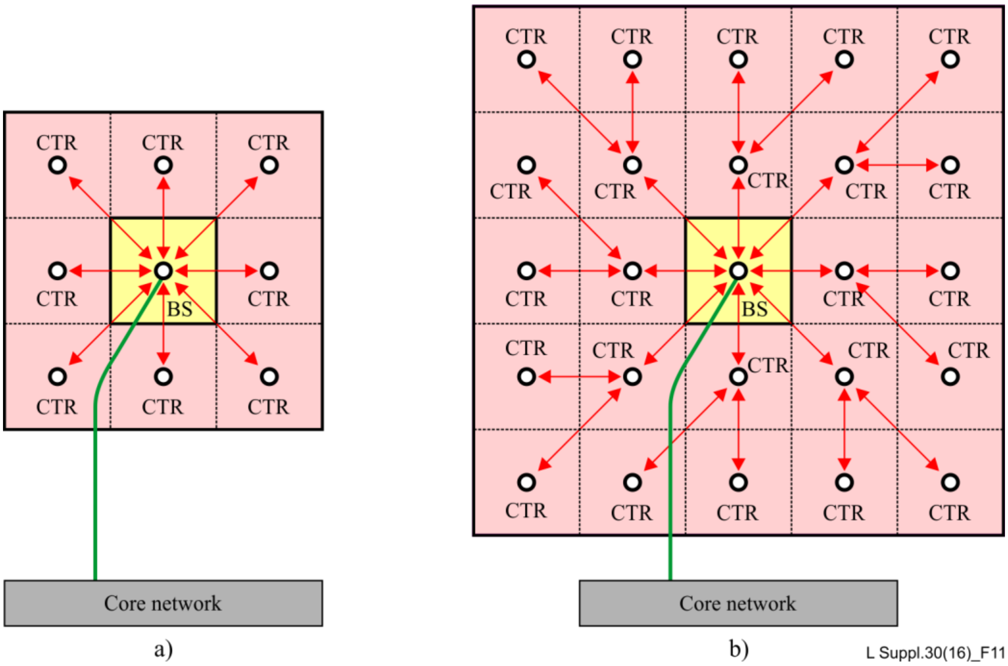

Figure 11 – Cellular network with capacity transfer for settlements

4.5 Capacity transfer repeater sharing

To reduce operator costs, in recent years the technology of various network elements sharing (network sharing) is often implemented by cellular operators worldwide. There can be a variety of options – from sharing the entire network infrastructure, including the radio subsystem and switching equipment to sharing the radio subsystem or a single BS.

The CTR technology fits well with this approach. In case of cooperative operations by network operators, the CTRs are installed on the network in the usual way as described previously. If operators use separate BSs installed at different sites, it is possible to deploy the CTR scheme as shown in Figure 12.

The use of CTRs for the implementation of the network sharing concept enables radio coverage on highways and in settlements separated from each other by a distance of up to 60 km for GSM and more than 100 km for UMTS and LTE.

The network scheme proposed in the previous paragraphs allows for each of the three operators to replace six BSs and six radio links for six shared repeaters, to reduce the number of towers and sites up to three times, to lower power consumption on site three to five times, to use lightweight masts, and to highly accelerate the construction of the network.

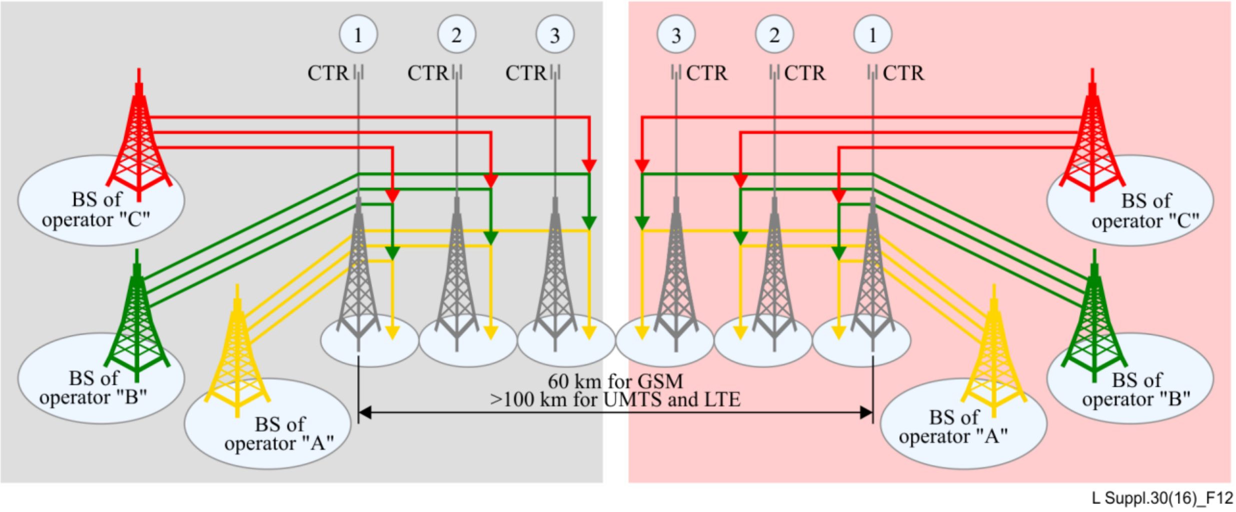

Figure 12 – Capacity transfer repeater sharing

4.6 Field test of a cellular system with capacity transfer

Field tests of a cellular network with capacity transfer, including RAN sharing mode – sharing of GSM CTRs by two commercial operators, was successfully completed in December 2015. Key conclusions of the test results follow.

– Tests confirmed that the characteristics of the GSM network with capacity transfer matched the performance of the commercial networks based on Alcatel Lucent and Huawei standard BSs in terms of: radio coverage area, network capacity, voice quality and transmission data rate. Compatibility with standard commercial GSM networks was achieved with CTRs. Successful voice calls from one operator's network to another and vice-versa was provided in the RAN sharing mode;

– The maximum communication range at which incoming and outgoing voice calls and data transmission were successful was around 11-15 km, depending on the height of the tower (50-75 m), while the transmitter power of the CTRs was 10 W and the transmitter power of standard BSs installed on the networks was 20 W;

– During the entire test period of the CTRs, data transmission via GPRS/EDGE channels was successful. When the distance between the MS and CTR was 7 km, the downlink data rate in EDGE mode was 170 kbit/s;

– Power consumption of the RC was less than 100 W, power consumption of the CTR, when both frequency channels were fully loaded, was less than 360 W, which is significantly less than the power consumed by standard BSs installed on commercial networks (3-5 kW);

– According to the test results, equipment of the GSM 900 cellular network type with capacity transfer is recommended for wide use by operators both on separate networks and on shared networks (RAN sharing).

5 Conclusion

CTR technology in the various scenarios described in this Supplement reduces the costs of network rollout and operation and while lowering energy consumption with a positive environment impact. Network CAPEX and OPEX savings may be reduced around three times each, depending on the particular scenario (the number of relay channels, the number of CTRs and their types). Power consumption of a CTR is less than 300 W, as confirmed by the field tests. The low power consumption of CTRs allows implementation of alternative power sources, creating eco-friendly "green" networks.

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