

METHODS FOR DETERMINING AN ACTIVATION SCHEME OF A RADIO COMMUNICATION DEVICE AND RADIO COMMUNICATION DEVICES

Cross-reference to Related Applications

[0001] The present application claims the benefit of the Singapore provisional patent application 201203478-1 filed on 11 May 2012, the entire contents of which are incorporated herein by reference for all purposes.

Technical Field

[0002] Embodiments relate generally to methods for determining an activation scheme of a radio communication device and radio communication devices.

Background

[0003] In cellular communication systems, each user may be served by its serving base station (BS). One major obstacle which may limit the spectrum efficiency (SE) in the cellular communication system may be the inter-cell interference from neighbouring BSs which are non-serving BSs. Specifically, the user located near the cell boundary suffers significantly larger interference from the neighbouring BSs compared to the users near the serving BS. Thus, there may be a need for devices and methods to enhance SE.

Summary

[0004] Various embodiments provide a method for determining an activation scheme of a radio communication device. The method may include determining a plurality of frames according to a multiple access scheme; and determining for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication.

[0005] Various embodiments provide a radio communication device. The radio communication device may include: a frame determination circuit configured to determine a plurality of frames according to a multiple access scheme; and an activation scheme determination circuit configured to determine for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication.

[0006] Various embodiments provide a radio communication device. The radio communication device may include a communication circuit configured to communicate with another radio communication device based on a frame structure including a plurality of communication frames. In each communication frame of the plurality of communication frames, the communication circuit is configured to be active in a pre-determined first portion of the communication frame and to be de-activated in a pre-determined second portion of the communication frame.

Brief Description of the Drawings

[0007] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments are described with reference to the following drawings, in which:

Fig. 1 shows an interference in a cellular system in the downlink transmission;

Fig. 2A shows a flow diagram illustrating a method for determining an activation scheme of a radio communication device according to various embodiments;

Fig. 2B shows a radio communication device according to various embodiments;

Fig. 2C shows a radio communication device according to various embodiments;

Fig. 2D shows a decision device according to various embodiments;

Fig. 3 shows an illustration of time varying nature of the traffic load within a 24-hour cycle;

Figs. 4A, 4B and 4C shows examples of BS (base station) behaviours;

Fig. 5 shows a time slot-based transmission with flickering pattern cycle of T according to various embodiments;

Fig. 6 shows examples of flickering pattern cycle T according to various embodiments for the case when 8 time slots are taken as a one transmission period;

Figs. 7A, 7B, 7C and 7D show examples of a flickering pattern according to various embodiments with $T = 3$;

Fig. 8 shows a diagram illustrating the relationship between $(m_{p^{(c)}}, v_{p^{(c)}})$ and traffic load;

Figs. 9A and 9B show examples of allocation patterns according to various embodiments;

Fig. 10 shows an illustrating of clustering of neighbouring BSs with $B=3$ according to various embodiments;

Fig. 11 shows a diagram illustrating a configuration of time slots and RBs with the flickering pattern length T ;

Figs. 12A and 12B show examples of intra-cluster interference and inter-cluster interference with $B=3$;

Figs. 13A and 13B show diagrams illustrating energy consumption of a communication system;

Fig. 14 shows a cluster layout according to various embodiments in a simulation.

Figs. 15A, 15B and 15C show diagrams illustrating a performance of the time slot based transmission according to various embodiments; and

Figs. 16A, 16B and 16C show diagrams illustrating an impact of the number of users according to various embodiments.

Description

[0008] Embodiments described below in context of the devices are analogously valid for the respective methods, and vice versa. Furthermore, it will be understood that the embodiments described below may be combined, for example, a part of one embodiment may be combined with a part of another embodiment.

[0009] In this context, the radio communication device as described in the various embodiments may include a memory which is for example used in the processing carried

out by the radio communication device. A memory used in the embodiments may be a volatile memory, for example a DRAM (Dynamic Random Access Memory) or a non-volatile memory, for example a PROM (Programmable Read Only Memory), an EPROM (Erasable PROM), EEPROM (Electrically Erasable PROM), or a flash memory, e.g., a floating gate memory, a charge trapping memory, an MRAM (Magnetoresistive Random Access Memory) or a PCRAM (Phase Change Random Access Memory).

[0010] In an embodiment, a "circuit" may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing software stored in a memory, firmware, or any combination thereof. Thus, in an embodiment, a "circuit" may be a hard-wired logic circuit or a programmable logic circuit such as a programmable processor, e.g. a microprocessor (e.g. a Complex Instruction Set Computer (CISC) processor or a Reduced Instruction Set Computer (RISC) processor). A "circuit" may also be a processor executing software, e.g. any kind of computer program, e.g. a computer program using a virtual machine code such as e.g. Java. Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a "circuit" in accordance with an alternative embodiment.

[0011] In cellular communication systems, each user may be served by its serving base station (BS). One major obstacle which limits the spectrum efficiency (SE) in the cellular communication system is the inter-cell interference from neighbouring BSs which are non-serving BSs as shown in FIG. 1.

[0012] FIG. 1 shows a diagram 100 illustrating interference in a cellular system in the downlink transmission. A serving BS 102, a first neighbouring BS 104 and a second

neighbouring BS 106 are shown. A plurality of users (like indicated exemplary by a circle 108) may be in communication with one or more of the base stations. For example, a user 110 in a coverage of the serving BS 102, may receive a desired signal (like indicated by a solid arrow) from the serving BS 102, and this may be interfered by undesired signals from the first neighbouring BS 104 and the second neighbouring BS 106, like indicated by dashed arrows.

[0013] For example, the user located near the cell boundary suffers significantly larger interference from the neighbouring BSs compared to the users near the serving BS. To overcome this problem, coordinated multi-point (CoMP) transmission, where neighbouring BSs cooperatively transmit/receive users' signals, may be provided. Furthermore, power efficiency (PE) or energy efficiency (EE) may be one of the important performance metrics of the cellular communication systems due to the high demand for energy saving. Therefore, the objective may be shifted from how to achieve the high SE to how to reduce the required power/energy while satisfying the quality-of-service (QoS) requirement. To improve the PE/EE, there is a need to carefully deal with the inter-cell interference.

[0014] FIG. 2A shows a flow diagram 200 illustrating a method for determining an activation scheme of a radio communication device according to various embodiments. In 202, a plurality of frames may be determined according to a multiple access scheme. In 204, for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication may be determined.

[0015] According to various embodiments, the method may further include: grouping a plurality of radio communication devices including the radio communication device to a cluster; and coordinating the determining of the first portion of the frame and the second portion of the frame based on an implicit coordination in the cluster.

[0016] According to various embodiments, the method may further include: the radio communication device transmitting information indicating its load status to a decision device; and the decision device determining the first portion of the frame and the second portion of the frame based on the information transmitted by the radio communication device.

[0017] According to various embodiments, the decision device may determine the first portion of the frame and the second portion of the frame based on a criterion on at least one of a communication condition of the radio communication device or current traffic load within a cluster.

[0018] According to various embodiments, the method may further include the radio communication device determining during which portions of a frame the neighbouring radio communication device is to perform communication, and during which portions of the frame during the neighbouring radio communication device is to not perform communication.

[0019] According to various embodiments, the multiple access scheme may include or may be at least one of the following multiple access schemes: a frequency-division multiple access (FDMA) scheme; a wavelength division multiple access (WDMA) scheme; an orthogonal frequency-division multiple access (OFDMA) scheme; a single-carrier FDMA (SC-FDMA) scheme; a linearly precoded OFDMA (LP-OFDMA)

scheme; a single-carrier frequency-domain-equalization (SC-FDE) access scheme; a time-division multiple access (TDMA) scheme; a multi-frequency time division multiple access (MF-TDMA) scheme; a code division multiple access (CDMA) scheme; a spread spectrum multiple access (SSMA) scheme; a direct-sequence CDMA (DS-CDMA) scheme; a direct-sequence spread spectrum (DSSS) scheme; a frequency-hopping CDMA (FH-CDMA) scheme; a Frequency-hopping spread spectrum (FHSS) scheme; an orthogonal frequency-hopping multiple access (OFHMA) scheme; a multi-carrier code division multiple access (MC-CDMA) scheme; a space division multiple access (SDMA) scheme; an Aloha scheme; a Slotted Aloha scheme; a multiple access with collision avoidance (MACA) scheme; a multiple access with collision avoidance for wireless (MACAW) scheme; a carrier sense multiple access (CSMA) scheme; a carrier sense multiple access with collision detection (CSMA/CD) scheme; a carrier sense multiple access with collision avoidance (CSMA/CA) scheme; a distributed coordination function (DCF) scheme; a carrier sense multiple access with collision avoidance and resolution using Priorities (CSMA/CARP) scheme; a carrier sense multiple access/bitwise arbitration (CSMA/BA) scheme; a token ring scheme; a token bus scheme; a polling scheme; a resource reservation (scheduled) packet-mode protocol scheme; a dynamic time division multiple access (Dynamic TDMA) scheme; a packet reservation multiple access (PRMA) scheme; and a reservation ALOHA (R-ALOHA) scheme.

[0020] According to various embodiments, determining for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication, may include determining

a flickering matrix indicating which of a plurality of base stations including the base station performs communication during which portion of the frame.

[0021] According to various embodiments, determining the flickering matrix may include determining a general flickering pattern matrix including indications of possible communication status for various portions of the frame.

[0022] According to various embodiments, determining the flickering matrix may further include determining a mapping matrix including indications of which possible communication status from the general flickering pattern matrix are to be selected.

[0023] According to various embodiments, each frame is divided into a plurality of slots. According to various embodiments, the first portion of the frame may include or may be a first subset of the slots. According to various embodiments, the second portion of the frame may include or may be a second subset of the slots.

[0024] According to various embodiments, the method may further include determining for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication, based on a communication condition of the radio communication device and/ or current traffic load (for example indicated by a call blocking ratio) within a cluster. A cluster may be a group of radio communication devices including the radio communication device.

[0025] According to various embodiments, the communication condition may include or may be at least one of a quality of service requirement of the radio communication device or a bandwidth requirement of the radio communication device.

[0026] According to various embodiments, the radio communication device may include or may be included in or may be a mobile radio base station.

[0027] FIG. 2B shows a radio communication device 206 according to various embodiments. The radio communication device 206 may include a frame determination circuit 208 configured to determine a plurality of frames according to a multiple access scheme. The radio communication device 206 may further include an activation scheme determination circuit 210 configured to determine for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication. The frame determination circuit 208 and the activation scheme determination circuit 210 may be coupled with each other, for example via a connection 212, for example an optical connection or an electrical connection, such as for example a cable or a computer bus or via any other suitable electrical connection to exchange electrical signals.

[0028] According to various embodiments, the activation scheme determination circuit 210 may further be configured to coordinate the determining of the first portion of the frame and the second portion of the frame based on an implicit coordination in a cluster including the radio communication device and a plurality of further radio communication devices.

[0029] According to various embodiments, the radio communication device 206 may further include a transmitter (not shown) configured to transmitting information indicating a load status of the radio communication device 206 to a decision device.

[0030] According to various embodiments, the radio communication device 206 may further include a neighbouring base station state determiner (not shown) configured to determining during which portions of a frame the neighbouring radio communication device is to perform communication, and during which portions of the frame during the neighbouring radio communication device is to not perform communication.

[0031] According to various embodiments, the multiple access scheme may include or may be at least one of the following multiple access schemes: a frequency-division multiple access (FDMA) scheme; a wavelength division multiple access (WDMA) scheme; an orthogonal frequency-division multiple access (OFDMA) scheme; a single-carrier FDMA (SC-FDMA) scheme; a linearly-coded OFDMA (LP-OFDMA) scheme; a single-carrier frequency-domain-equalization (SC-FDE) access scheme; a time-division multiple access (TDMA) scheme; a multi-frequency time division multiple access (MF-TDMA) scheme; a code division multiple access (CDMA) scheme; a spread spectrum multiple access (SSMA) scheme; a direct-sequence CDMA (DS-CDMA) scheme; a direct-sequence spread spectrum (DSSS) scheme; a frequency-hopping CDMA (FH-CDMA) scheme; a Frequency-hopping spread spectrum (FHSS) scheme; an orthogonal frequency-hopping multiple access (OFHMA) scheme; a multi-carrier code division multiple access (MC-CDMA) scheme; a space division multiple access (SDMA) scheme; an Aloha scheme; a Slotted Aloha scheme; a multiple access with collision avoidance (MACA) scheme; a multiple access with collision avoidance for wireless (MACAW) scheme; a carrier sense multiple access (CSMA) scheme; a carrier sense multiple access with collision detection (CSMA/CD) scheme; a carrier sense multiple access with collision avoidance (CSMA/CA) scheme; a distributed coordination function

(DCF) scheme; a carrier sense multiple access with collision avoidance and resolution using Priorities (CSMA/CARP) scheme; a carrier sense multiple access/bitwise arbitration (CSMA/BA) scheme; a token ring scheme; a token bus scheme; a polling scheme; a resource reservation (scheduled) packet-mode protocol scheme; a dynamic time division multiple access (Dynamic TDMA) scheme; a packet reservation multiple access (PRMA) scheme; and a reservation ALOHA (R-ALOHA) scheme.

[0032] According to various embodiments, the activation scheme determination circuit is further configured to determine a flickering matrix indicating which of a plurality of base stations including the base station performs communication during which portion of the frame.

[0033] According to various embodiments, the activation scheme determination circuit 210 may further be configured to determine a general flickering pattern matrix including indications of possible communication status for various portions of the frame.

[0034] According to various embodiments, the activation scheme determination circuit 210 may further be configured to determine a mapping matrix including indications of which possible communication status from the general flickering pattern matrix are to be selected.

[0035] According to various embodiments, each frame may be divided into a plurality of slots. According to various embodiments, the first portion of the frame may include or may be a first subset of the slots. According to various embodiments, the second portion of the frame may include or may be a second subset of the slots.

[0036] According to various embodiments, the activation scheme determination circuit 210 may further be configured to determine for each frame of the plurality of

frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication, based on a communication condition of the radio communication device and/ or current traffic load (for example indicated by a call blocking ratio) within a cluster. A cluster may be a group of radio communication devices including the radio communication device.

[0037] According to various embodiments, the communication condition may include or may be at least one of a quality of service requirement of the radio communication device or a bandwidth requirement of the radio communication device.

[0038] According to various embodiments, the radio communication device 206 may include or may be included in or may be a mobile radio base station.

[0039] FIG. 2C shows a radio communication device 214 according to various embodiments. The radio communication device 214 may include a communication circuit 216 configured to communicate with another radio communication device based on a frame structure including a plurality of communication frames. In each communication frame of the plurality of communication frames, the communication circuit 216 may be configured to be active in a pre-determined first portion of the communication frame and to be de-activated in a pre-determined second portion of the communication frame.

[0040] According to various embodiments, the radio communication device 214 may include or may be included in or may be a mobile radio base station.

[0041] FIG. 2D shows a decision device 218 according to various embodiments. The decision device 218 may include a grouping circuit 220 configured to group a plurality of radio communication devices including the radio communication device to a cluster. The

decision device 218 may further include a coordination circuit 222 configured to determine for each frame according to a multiple access scheme a first portion of the frame, during which a radio communication device is allowed to perform communication, and a second portion of the frame during which the radio communication device is not allowed to perform communication. The grouping circuit 220 and the coordination circuit 222 may be coupled with each other, for example via a connection 224, for example an optical connection or an electrical connection, such as for example a cable or a computer bus or via any other suitable electrical connection to exchange electrical signals.

[0042] According to various embodiments, the decision device 218 may further include a receiver (not shown) configured to receive from the radio communication device information indicating the load status of the radio communication device. The coordination circuit 222 may further be configured to determine the first portion of the frame and the second portion of the frame based on the information transmitted by the radio communication device.

[0043] According to various embodiments, the coordination circuit 222 may further be configured to determine the first portion of the frame and the second portion of the frame based on a criterion on at least one of a communication condition of the radio communication device or current traffic load within a cluster.

[0044] FIG. 3 shows an illustration 300 of time varying nature of the traffic load within a 24-hour cycle.

[0045] The traffic load of the cellular communication systems may have dynamic nature in both time and space (location), i.e., it may vary from time to time as shown in FIG. 3 and it may depend also on the location.

[0046] FIG. 4A, FIG. 4B, FIG. 4C show examples of BS behaviours. FIG. 4A shows an illustrating 400 of a BS behaviour in a commonly used system. Various BSs and the corresponding coverage area (indicated by a circle) are shown for various time slots 404, 406, 408, 410. The BS behaviour is indicated by a symbol in the centre of the respective circle; for example, a square BS (like shown in 402) may indicate that the transmitter (TX) of the BS is in transmission mode. It can be seen that all BS are in TX mode during all time slots.

[0047] FIG. 4B shows an illustration 412 for a BS deactivation strategy, where the TX of the BS may be in active mode (like indicated by square box 414) or in sleep mode (like indicated by triangle 416) for various time slots 418, 420, 422, 424. It can be seen that during each BS has the same mode during all slots (either active in all modes or sleep in all modes).

[0048] FIG. 4C shows an illustration 426 for a fractional time reuse (FTR) strategy according to various embodiments, where the TX of the BS may either be in transmit mode (like indicated by circle 428) or in nap mode (like indicated by star 430) for various time slots 432, 434, 436, 438. It can be seen that each base station may change the mode (or state; for example transmit mode or nap mode) of its TX from one slot to the next slot (or may keep the state unchanged).

[0049] Under a high traffic load condition, almost all the resources (e.g., time, frequency, and space) may be desired to be utilized to satisfy the traffic demands. Accordingly, all BSs may be activated as shown in FIG. 4A.

[0050] On the other hand, under a low traffic load condition, only the part of the resources may be necessary to satisfy the QoS requirement. Hence, it may be possible to reduce the energy/power consumption by appropriately managing the usage of the resources while guaranteeing the QoS requirement. Network power saving may be effectively achieved by reducing power consumption of BSs who are the major power consumers in the networks. So far, several research studies have been conducted to reduce power consumption of the cellular communication systems when the traffic load is low. However, the commonly used schemes may lack of dynamic nature of the traffic and the major problem of cellular communication system, i.e., inter-cell interference, still may remain.

[0051] According to various embodiments, devices and methods may be provided for fractional time reuse for energy saving of wireless networks.

[0052] According to various embodiments, a time slot-based transmission which may be referred to as a FTR scheme for wireless networks with multiple TXs in a cluster may be provided. One transmission period (e.g., super frame or frame) may be divided into multiple orthogonal time slots. Each time slot may be allocated to the multiple TXs in a cluster according to a time slot allocation pattern. The time slot allocation pattern may include ones and zeros indicating a transmit mode and a nap mode, respectively. In the transmit mode, a TX may transmit signals to the corresponding receiver as usual, while in the nap mode, the TX may stand by to transmit whenever it is requested to transmit. The

proposed new communication protocol according to various embodiments based on the time slot allocation pattern may be referred to as a non-transmitting adaptive protocol (NAP) as it may control non-transmitting (i.e., nap) mode adaptively according to the time slot allocation pattern. Since the time slot allocation pattern, which may include ones and zeros indicating a transmit mode and a nap mode, allows the TX to flicker (transmission-to-nap or nap-to-transmission), it may also be referred to as a flickering pattern. A basic principle to determine the flickering pattern may be to induce the more ones in the pattern if the loading factor is high. According to various embodiments, various flickering patterns may be provided such as a random pattern for simplicity and an orthogonal pattern for minimum interferences between TXs. Based on the flickering pattern, the TXs may nap if the allocation pattern is zero, i.e., loading factor is low, so the network power consumption may be reduced, and at the same time, the interferences to neighbouring TXs may be reduced as well. From the numerical results in a cellular network that is a major application of the proposed FTR, the simplest NAP (with an orthogonal flickering patterns) can achieve significant energy saving, i.e., less than 50% of the commonly used system, with sustaining the same quality-of-service (QoS) as the commonly used transmit protocol in which all TXs in a cluster in the networks keep transmitting.

[0053] To reduce the network energy consumption and to solve the inter-cell interference issue, according to various embodiments, a FTR scheme may be provided, which may be realized by a time slot-based transmission including two modes: transmit mode and nap mode. One transmission period (e.g., super frame or frame) may be divided into multiple orthogonal time slots. Each time slot may be independently

allocated to multiple TXs according to the time slot allocation pattern, which may include ones and zeros indicating a transmit mode and a nap mode, respectively. In the transmit mode, the TX may transmit a signal to its corresponding receivers (RXs) as usual, while in the nap mode, the TX may stand by for the quick transition to the transmit mode immediately; thus, the latter mode may be referred to as a nap mode. The nap mode may be different from a sleep or idle mode in the commonly used communication protocols, in which the TX is turned off for long time period as illustrated in FIG. 4B. The protocol according to various embodiments may be referred to as a non-transmitting (i.e., nap) adaptive protocol (NAP) as the transmit mode and the nap mode may be adaptively controlled by the time slot allocation pattern.

[0054] Each time slot may be independently assigned for the transmit mode or the nap mode according to time slot allocation pattern indicating slot's mode. The time slot allocation pattern may be determined by a central unit (CU), which may also be referred to as a decision device, which collects the loading factor of each BSs. The CU may be one of the BSs within a cluster or other network entity to which each BS is connected. As shown FIG. 4C, a TX with NAP may switch its mode in each time slot as if it is flickering. Henceforth, the time slot allocation pattern may be referred to as a flickering pattern. The BSs using the NAP may be referred to as a flickering BS. For example, a principle to determine the flickering pattern may be to induce more 1s in the pattern if the loading factor is high. According to various embodiments, a general flickering pattern matrix including an orthogonal pattern may be provided. The orthogonal pattern may reduce the inter-cell interferences, which may be a major problem of cellular communication systems.

[0055] For example, the FTR according to various embodiments may be used in a cellular network. The time slot-based transmission with flickering pattern according to various embodiments may be interpreted as a generalized time division multiplexing (TDM) as the transmission from each BS is not necessarily orthogonal. The BS using the NAP may be referred to as a flickering BS. Different from the commonly used BS deactivating approaches, no BS may be deactivated or in sleep mode, and there may be no explicit cooperation among BSs as in the commonly used methods. The instantaneous transmission rate per time slot may be desired to be increased compared to non-slotted approach due to the shorter transmission duration. Hence, larger transmission power or allocation of larger number of frequency domain resource blocks (RBs) to each user may be desired to satisfy the QoS requirement. On the other hand, the interference from the neighbouring BSs may be effectively reduced through the NAP. This in turn may compensate for the requirement of the instantaneous transmission rate increased due to the shorter transmission duration.

[0056] To implement the slot-based transmission according to various embodiments in practical cellular communication system, the neighbouring BSs may form a cluster. The time slot allocation may be performed within each cluster. The adaptive BS clustering and adaptive time slot clustering approaches may also be provided. For example, the orthogonal slot allocation scheme may be described by using the case when each cluster is composed of three neighbouring BSs. However, it will be understood that any other number of BS may be provided in a cluster, and that dynamic assignment of BSs to a cluster may be provided. The power consumption model may be provided as a

function of the traffic load. The power consumption of a BS during the nap mode may also be taken into account for performance evaluation.

[0057] The energy efficiency of the approach according to various embodiments may be evaluated by computer simulation. In simulation results, the energy saving gain of the proposed NAP compared to the commonly used protocols may be observed. As will be described in more detail below, the energy consumption of BS may be reduced to less than 50% of the commonly used system while satisfying the QoS requirement.

[0058] The merits of the NAP according to various embodiments may be summarized as follows:

[0059] A) Simple Networking: No signalling between BSs may be desired, and handovers may occur less frequently.

[0060] B) Interference Reduction: BS in nap mode may not interfere with neighbouring BSs, which resolves a low QoS issue of cell-edge users.

[0061] C) Adaptability: NAP may adapt the slot pattern according to the dynamic traffic load.

[0062] D) Backward Compatibility: No changes in physical layer protocols and algorithms may be desired.

[0063] In the following, FTR via time slot based transmission with flickering pattern matrix according to various embodiments will be described.

[0064] Different from the BS deactivating approaches, no BS may be deactivated and there may be no explicit cooperation among BSs in the FTR strategy. According to various embodiments, a time slot based transmission may be provided, which may utilize a flickering pattern matrix and a mapping matrix to realize the FTR strategy. One

transmission period (e.g., super frame or frame) may be divided into T orthogonal time slots of equal duration, where T may be referred to as a flickering pattern cycle, as shown in FIG. 5.

[0065] FIG. 5 shows a diagram 500 illustrating a time slot-based transmission with flickering pattern cycle of T according to various embodiments. Time may be assumed to run from left to right, like indicated by arrow 502. For example various flickering pattern cycles 504 may be provided (for example each corresponding to a frame or a super frame according to a multiple access scheme). Each flickering pattern cycle may include a pre-determined number of slots (for example T slots, wherein in FIG. 5 as an example the first slot 506, the t -th slot 508, and the T -th slot 510 are shown). The slots of FIG. 5 may refer to the slots shown in FIG. 4C.

[0066] Each BS may only transmit the signal to the users within its coverage area during the certain time slot.

[0067] FIG. 6 shows an illustration 600 of an example of how to split one transmission period into length T flickering pattern cycle. The flickering pattern cycle may depend on the system requirement and hardware complexity. FIG. 6 shows examples of flickering pattern cycle T according to various embodiments for the case when 8 time slots 602 are taken as a one transmission period: (a) $T=8$ (b) $T=4$ (c) $T=2$. A dark gray box (like box 604) may indicate a transmit mode slot, and a light gray box (like box 606) with a diagonal line may indicate a nap mode slot.

[0068] A general flickering pattern matrix may be a Q -by- T binary matrix and may be denoted by F_G , which may capture the operation of BSs during flickering pattern

cycle T . Since $\mathbf{F}_G$ is a binary matrix, the whole pattern can be covered by setting $Q = 2^T$, which may denote the total number of flickering patterns. $\mathbf{F}_G$ may be expressed as

$$\mathbf{F}_G = \begin{pmatrix} \mathbf{f}_1^T \\ \vdots \\ \mathbf{f}_q^T \\ \vdots \\ \mathbf{f}_Q^T \end{pmatrix} = \begin{pmatrix} f_{1,1} & \cdots & f_{1,t} & \cdots & f_{1,T} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ f_{q,1} & & f_{q,t} & & f_{q,T} \\ \vdots & & \vdots & \ddots & \vdots \\ f_{Q,1} & \cdots & f_{Q,t} & \cdots & f_{Q,T} \end{pmatrix} \quad (1)$$

where $\mathbf{f}_q = (f_{q,1} \cdots f_{q,t} \cdots f_{q,T})^T$ may be the T -by-1 flickering pattern binary column vector and the element $f_{q,t} \in \{1,0\}$ may denote the operation of BS at time slot t . If $f_{q,t} = 1$, the BS may be in transmit mode in time slot t . Otherwise may be in nap mode.

[0069] The example of the general flickering pattern matrix $\mathbf{F}_G$ with $T = 3$ may be given as (like also illustrated in FIG. 7A):

$$\mathbf{F}_G = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \end{pmatrix}^T \quad (2)$$

[0070] The flickering pattern matrix may be any subset of the general flickering pattern matrix $\mathbf{F}_G$.

[0071] In the following, two examples of flickering pattern matrices will be described.

[0072] A) In an *orthogonal flickering pattern matrix*, only one element of each column of the flickering matrix may be one, and remaining elements may be zero, for example as follows:

$$\mathbf{F}_{\text{orth}} = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix} \text{ and } \mathbf{F}_{\text{orth}} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix} \quad (3)$$

Therefore, each time slot is assigned to only one BS.

[0073] In a random flickering pattern matrix, each row may be randomly extracted from the $\mathbf{F}_G$. For example, a random flickering pattern matrix may be as follows:

$$\mathbf{F}_{\text{random}} = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 1 & 0 \end{pmatrix} \text{ and } \mathbf{F}_{\text{random}} = \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix} \quad (4)$$

Therefore, each time slot can be assigned to one or more than one BSs.

[0074] A flickering matrix for BSs may be defined as

$$\mathbf{S} = (\mathbf{s}_1 \quad \cdots \quad \mathbf{s}_b \quad \cdots \quad \mathbf{s}_B)^T, \quad (5)$$

where $\mathbf{s}_b$ may be a length T binary column vector which represents the flickering pattern of BS $b \in \{1, \dots, B\}$ with B representing the number of BSs.

[0075] A B -by- Q general binary mapping matrix $\mathbf{M}_G$ may be defined as

$$\mathbf{M}_G = (\mathbf{e}_{i_1} \quad \cdots \quad \mathbf{e}_{i_b} \quad \cdots \quad \mathbf{e}_{i_B})^T, \quad (6)$$

where $\mathbf{e}_i$ may be a Q -by-1 column vector with a 1 at the i th element and 0's elsewhere.

[0076] Then, a mapping from the general flickering pattern matrix $\mathbf{F}_G$ to $\mathbf{S}$ may be performed as follows:

$$\begin{aligned} \mathbf{S} &= (\mathbf{s}_1 \quad \cdots \quad \mathbf{s}_b \quad \cdots \quad \mathbf{s}_B)^T \\ &= \underbrace{(\mathbf{e}_{i_1} \quad \cdots \quad \mathbf{e}_{i_b} \quad \cdots \quad \mathbf{e}_{i_B})^T}_{\mathbf{M}_G} \underbrace{(\mathbf{f}_1 \quad \cdots \quad \mathbf{f}_q \quad \cdots \quad \mathbf{f}_Q)^T}_{\mathbf{F}_G} \\ &= (\mathbf{f}_{i_1} \quad \cdots \quad \mathbf{f}_{i_b} \quad \cdots \quad \mathbf{f}_{i_B})^T \end{aligned} \quad (7)$$

[0077] The flickering pattern f_{ib} may be assigned to BS b .

[0078] Let us consider the case when the number of BSs and the flickering pattern length is set to $B=3$ and $T=3$, respectively. The 8-by-3 general flickering matrix may then become

$$\begin{aligned} \mathbf{F}_G &= (\mathbf{f}_1 \ \mathbf{f}_2 \ \mathbf{f}_3 \ \mathbf{f}_4 \ \mathbf{f}_5 \ \mathbf{f}_6 \ \mathbf{f}_7 \ \mathbf{f}_8)^T \\ &= \begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \end{pmatrix}^T \end{aligned} \quad (8)$$

[0079] FIGS. 7A, 7B, 7C and 7D show examples of a flickering pattern according to various embodiments with $T=3$. A dark gray box (like box 706) may indicate a transmit mode slot, and a light gray box with a diagonal line (like box 708) may indicate a nap mode slot.

[0080] FIG. 7A shows an illustration 700 of the flickering pattern 704 according to equation (8), wherein the matrix 702 of equation (8) is also shown.

[0081] Some examples of mapping matrix and the corresponding flickering pattern are given as follows.

[0082] FIG. 7B shows an illustration 720 of a further example.

In the example, the mapping matrix may be:

$$\mathbf{M}_1 = (\mathbf{e}_2 \ \mathbf{e}_3 \ \mathbf{e}_5)^T$$

In the example, the flickering matrix may be:

$$\begin{aligned} \mathbf{S}_1 &= \mathbf{M}_1 \mathbf{F}_G \\ &= \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix} \mathbf{F}_G \\ &= \begin{pmatrix} \mathbf{f}_2^T \\ \mathbf{f}_3^T \\ \mathbf{f}_5^T \end{pmatrix} = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix} \end{aligned}$$

[0083] FIG. 7C shows a an illustration 740 of a further example.

In the example, the mapping matrix may be:

$$\mathbf{M}_2 = (\mathbf{e}_4 \quad \mathbf{e}_5 \quad \mathbf{e}_7)^T$$

In the example, the flickering matrix may be:

$$\begin{aligned} \mathbf{S}_2 &= \mathbf{M}_2 \mathbf{F}_G \\ &= \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix} \mathbf{F}_G \\ &= \begin{pmatrix} \mathbf{f}_4^T \\ \mathbf{f}_5^T \\ \mathbf{f}_7^T \end{pmatrix} = \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix} \end{aligned}$$

[0084] FIG. 7D shows a an illustration 760 of a further example.

In the example, the mapping matrix may be:

$$\mathbf{M}_3 = (\mathbf{e}_7 \quad \mathbf{e}_4 \quad \mathbf{e}_6)^T$$

In the example, the flickering matrix may be:

$$\begin{aligned} \mathbf{S}_3 &= \mathbf{M}_3 \mathbf{F}_G \\ &= \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix} \mathbf{F}_G \\ &= \begin{pmatrix} \mathbf{f}_7^T \\ \mathbf{f}_4^T \\ \mathbf{f}_6^T \end{pmatrix} = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{pmatrix} \end{aligned}$$

[0085] In the following, embodiments for the implementation of the time slot based transmission with flickering pattern matrix according to various embodiments into cellular communication systems will be described.

[0086] The BSs may be divided into non-overlapping multiple clusters, which may be of any shape such as regular cluster and irregular cluster. The cluster set may be denoted by $\mathcal{C}$. For simplicity, the number of BSs within each cluster may be assumed to be the same and denoted by B (however, it will be understood that any number of BSs may be in

every cluster, and that the numbers of BS in different clusters may be different), and the BS set within cluster c may be denoted by $\mathcal{B}_c$, i.e., $|\mathcal{B}_c| = B$. Let us focus on cluster c . The traffic load of BS $b^{(c)} \in \mathcal{B}_c$ may be expressed by $\rho_{b^{(c)}}$, which may be normalized by the maximum affordable traffic, and without loss of generality $\rho_{1^{(c)}} \geq \dots \geq \rho_{b^{(c)}} \geq \dots \geq \rho_{B^{(c)}}$ is assumed.

[0087] The combination of the general flickering pattern matrix $\mathbf{F}_G$ and the mapping matrix $\mathbf{M}_G$ may allow each time slot to be allocated to multiple BSs. Hence, the proposed strategy may adapt to the time-varying traffic and spatial-varying traffic, i.e., different traffic load for different BSs. When the traffic load of a BS is high (low), more (less) time slots may be desired to be allocated to the BS.

[0088] Here, let us define the following metrics, i.e., mean value of the traffic load and variance of the traffic load within the cluster as follows:

$$\begin{cases} m_{\rho^{(c)}} = \frac{1}{B} \sum_{b^{(c)} \in \mathcal{B}_c} \rho_{b^{(c)}} \\ v_{\rho^{(c)}} = \frac{1}{B} \sum_{b^{(c)} \in \mathcal{B}_c} \left| \rho_{b^{(c)}} - m_{\rho^{(c)}} \right|^2 \end{cases} \quad (9)$$

[0089] The mean $m_{\rho^{(c)}}$ may indicate the time varying nature of the traffic and the variance $v_{\rho^{(c)}}$ may indicate the spatial variation of the traffic load. For example, when $m_{\rho^{(c)}}$ is small and $v_{\rho^{(c)}}$ is small (large), the system traffic load may be low and the geographical dependency of the traffic load may be small (large). One example is illustrated in FIG. 8 with $B = 3$ and the flickering pattern cycle $T = 3$.

[0090] FIG. 8 shows a diagram 800 illustrating the relationship between $(m_{\rho(c)}, v_{\rho(c)})$ and traffic load. $m_{\rho(c)}$ may be indicated on a horizontal axis 802, and $v_{\rho(c)}$ may be indicated on a vertical axis 804.

[0091] When $m_{\rho(c)}$ is small but $v_{\rho(c)}$ is large, i.e., $\rho_{1(c)} > \rho_{2(c)} > \rho_{3(c)}$, it may be desired to allocate more time slots to the BS with high traffic load while allocating less time slots to the BS with low traffic load. Let us consider the general flickering matrix F_G . By setting the mapping matrix for example as

$$\mathbf{M}_4 = (\mathbf{e}_{57} \quad \mathbf{e}_7 \quad \mathbf{e}_2)^T, \quad (10)$$

the following flickering matrix for BSs within cluster c may be obtained (like illustrated in FIG. 9A):

$$\mathbf{S}_c = \begin{pmatrix} \mathbf{s}_{1(c)}^T \\ \mathbf{s}_{2(c)}^T \\ \mathbf{s}_{3(c)}^T \end{pmatrix} = \begin{pmatrix} \mathbf{f}_{57}^T \\ \mathbf{f}_7^T \\ \mathbf{f}_2^T \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}. \quad (11)$$

[0092] On the other hand, when $m_{\rho(c)}$ is small and $v_{\rho(c)}$ is also small, i.e., $\rho_{1(c)} \approx \rho_{2(c)} \approx \rho_{3(c)}$, it may be desired to allocate the same number of time slots to all the BSs.

[0093] By setting the mapping matrix for example as

$$\mathbf{M}_5 = (\mathbf{e}_{49} \quad \mathbf{e}_{13} \quad \mathbf{e}_4)^T, \quad (12)$$

the following flickering matrix (like illustrated in FIG. 9B) may be obtained:

$$\mathbf{S}_c = \begin{pmatrix} \mathbf{s}_{1(c)}^T \\ \mathbf{s}_{2(c)}^T \\ \mathbf{s}_{3(c)}^T \end{pmatrix} = \begin{pmatrix} \mathbf{f}_{49}^T \\ \mathbf{f}_{13}^T \\ \mathbf{f}_4^T \end{pmatrix} = \begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \end{pmatrix}. \quad (13)$$

[0094] FIGS. 9A and 9B show examples of allocation patterns according to various embodiments with $|\mathcal{B}|=3$ and $T=6$. FIG. 9A show a diagram 900 illustrating an example when the variance of traffic load is large ($\rho_{1(c)} > \rho_{2(c)} > \rho_{3(c)}$), wherein a flickering matrix 902 and the resulting flickering pattern cycle 904 are shown. FIG. 9B shows a diagram 906 illustrating an example when the variance of traffic load is small ($\rho_{1(c)} \approx \rho_{2(c)} \approx \rho_{3(c)}$), wherein a flickering matrix 908 and the resulting flickering pattern cycle 910 are shown.

[0095] Devices and methods according to various embodiments may be applied for network energy saving. Practical application of the time slot based transmission with flickering pattern matrix according to various embodiments will be described in the following. The strategy may be utilized to save the network energy of the cellular communication system.

[0096] According to various embodiments, an orthogonal flickering pattern matrix may be provided. According to various embodiments, a fixed mapping matrix may be provided.

[0097] The BSs may be divided into non-overlapping cluster sets $\mathcal{C}$. The BS set within cluster c may be denoted by $\mathcal{B}_c$, where each cluster may be formed by neighbouring B BSs, i.e., $|\mathcal{B}_c|=B$. An example of cluster size $B=3$ is shown in FIG. 10.

[0098] FIG. 10 shows an illustration 1000 of clustering of neighbouring BSs with $B=3$ according to various embodiments. An exemplary cluster is indicated by reference sign 1002.

[0099] The flickering pattern cycle may be set to $T = B$ and each time slot may be composed of M orthogonal RBs as shown in FIG. 11.

[00100] FIG. 11 shows a diagram 1100 illustrating a configuration of time slots and RBs with the flickering pattern length T .

[00101] If the slot is allocated to a BS, then the BS may transmit during that slot. Each BS may change its mode, i.e., transmit mode or nap mode, at each slot.

[00102] For simplicity and complete elimination of inter-cluster interference, for example the following flickering pattern matrix and fixed mapping matrix may be used:

Orthogonal Flickering Pattern Matrix:

$$\mathbf{F}_{\text{orth}} = \mathbf{I}_{B \times B} \quad (14)$$

Fixed Mapping Matrix

$$\mathbf{M}_{\text{fix}} = \mathbf{I}_{B \times B} \quad (15)$$

where $\mathbf{I}_{B \times B}$ may denote the B -by- B identity matrix.

[00103] During the time slots to which BS is not allocated, it may not transmit signals, hence no interference may be generated from it. Ideally, the power consumption of BS may be 0. However, some circuits may still consume certain amount of power during the nap mode slot.

[00104] FIGS. 12A and 12B show examples of intra-cluster interference and inter-cluster interference with $B=3$. In FIG. 12A, an illustration 1200 for a non-slotted transmission is shown with a first cluster 1202 and a second cluster 1204. In FIG. 12B, an

illustration 1208 for a slot based transmission with orthogonal flickering pattern is shown with a first cluster 1210 and a second cluster 1212.

[00105] As shown in FIG. 12A, there may be both intra-cluster interference and inter-cluster interferences for the commonly used system like indicated by arrows 1206, i.e., non-slotted transmission as all the BSs are transmitting during whole time slots. On the other hand, the time slot based transmission with orthogonal flickering pattern may completely eliminate the intra-cluster interference and reduce the inter-cluster interference as illustrated in FIG. 12B by arrow 1214.

[00106] In the following, user grouping based on signal-to-interference plus noise ratio (SINR) will be described.

[00107] Let us focus on the user u in cluster c . During the training phase, each BS may transmit the training signal. The training signal for each time slot may be transmitted using orthogonal resources such as frequency, time, or code. User u may calculate the signal-to-interference plus noise power ratio (SINR) for each BS and time slot as

$$\gamma_{u,(b^{(c)},t)} = \frac{P_{\max} G_{u,b^{(c)}}}{I_{u,(b^{(c)},t)} + \sigma_n}, \quad (16)$$

where $P_{\max}$ may be the maximum transmission power at each BS, $G_{u,b^{(c)}}$ may be the channel gain between user u and BS b in cluster c , which may be assumed to be constant during one flickering pattern cycle, $I_{u,(b^{(c)},t)}$ may be the interference, and σ_n may be the AWGN (Additive white Gaussian noise) power.

[00108] The channel gain $G_{u,b^{(c)}}$ may be given as

$$10\log_{10} G_{u,b^{(c)}} = A(\psi_{u,b^{(c)}}) + PL_{u,b^{(c)}} + \eta_{u,b^{(c)}}, \quad (17)$$

where $A(\psi_{u,b(c)})$ may denote the antenna gain, $PL_{u,b(c)}$ may denote the distance dependent path loss, and $\eta_{u,b(c)}$ may be the log-normally distributed shadowing loss with the standard deviation of σ (dB) between user u and BS b within cluster c .

[00109] The interference term $I_{u,(b(c),t)}$ may be decomposed into two parts as follows:

$$I_{u,(b(c),t)} = I_{u,(b(c),t)}^{\text{intra}} + I_{u,(b(c),t)}^{\text{inter}}, \quad (18)$$

where the first term $I_{u,(b(c),t)}^{\text{intra}}$ may denote the intra-cluster interference from other BSs in the same cluster and the second term $I_{u,(b(c),t)}^{\text{inter}}$ may denote the inter-cluster interference from other clusters, and they may be given as

$$\begin{cases} I_{u,(b(c),t)}^{\text{intra}} = P_{\max} \times \sum_{b'(c) \in \{B_c \setminus b(c)\}} f_{b'(c),t} G_{u,b'(c)} \\ I_{u,(b(c),t)}^{\text{inter}} = P_{\max} \times \sum_{c' \in \{C \setminus c\}} \sum_{b(c') \in B_{c'}} f_{b(c'),t} G_{u,b(c')} \end{cases} \quad (19)$$

[00110] Based on the calculated SINR, the user may decide the connecting BS and the time slot. Hence, the following user group may be identified by the BS index and the time slot index as

$$(\tilde{b}^{(c)}, \tilde{t}) = \arg \max_{b(c) \in B_c, t \in \mathcal{T}_{tx}} \gamma_{u,(b(c),t)}. \quad (20)$$

where $\mathcal{T}_{tx}$ denotes the time index set where $f_{b_c,t} = 1$.

[00111] In the following, frequency domain RB (resource block) allocation according to various embodiments will be described.

[00112] For example, only the large scale fading effect may be considered. The frequency selective fading may not be considered to evaluate the potential benefit of slot based transmission according to various embodiments. The user may connect to the BS

with the highest SINR, and this approach may correspond to dynamic cell selection (DCS) of CoMP (coordinate multi-point) transmission. Here, the target rate may be taken as a QoS (quality of service) requirement. Since the RB allocation information at each BS may not be shared among the BSs, the BS may allocate enough number of RBs to each user such that the target rate may be achieved even under the intra-cluster and inter-cluster interferences. For frequency domain user scheduling, a round robin (RR) scheduler may be used. It is to be noted that any existing user scheduling algorithm may be incorporated into the slot based transmission according to various embodiments.

[00113] The required number of RBs to achieve target rate R_u^{tar} may be determined as

$$M_{u,(\tilde{b}^{(c)},\tilde{t})}^{\text{req}} = \left\lceil \frac{R_u^{\text{tar}}}{R_{u,(\tilde{b}^{(c)},\tilde{t})}} \right\rceil, \quad (21)$$

where $\lceil x \rceil$ may denote the smallest integer larger than or equal to x and

$$R_{u,(\tilde{b}^{(c)},\tilde{t})} = \frac{1}{T} \times \frac{W_{\text{total}}}{M} \times \log_2 \left(1 + \frac{P_{\text{max}} G_{u,\tilde{b}^{(c)}}}{I_{u,(\tilde{b}^{(c)},\tilde{t})} + \sigma_n} \right). \quad (22)$$

[00114] RBs may be allocated to each user in a random manner. This allocation may be valid due to independent frequency selective fading channel experienced by each user. The maximum number of RBs per BS which may be allocated to users may be M , hence some of the users may not be able to be accommodated. Those users may be considered to be blocked.

[00115] Hence, traffic load of BS b during time slot t may become

$$\rho_{b,t}^{(c)} = \frac{1}{M} \sum_u S_u(b^{(c)},t) \times M_{u,(b^{(c)},t)}^{\text{req}} = \frac{1}{M} \sum_u S_u(b^{(c)},t) \times \left\lceil \frac{R_u^{\text{tar}}}{R_{u,(b^{(c)},t)}} \right\rceil, \quad (23)$$

where $S_u(b^{(c)}, t)$ may be an indicator function indicating whether user u may be connected to BS b in cluster c during time slot t , which may be given as

$$S_u(b^{(c)}, t) = \begin{cases} 1 & \text{if } (b^{(c)}, t) = \arg \max_{b^{(c)}, t'} \gamma_{u, (b^{(c)}, t')} \\ 0 & \text{otherwise} \end{cases} \quad (24)$$

[00116] Hence, the energy consumption of cluster c during one flickering pattern cycle may be is given as

$$E^{\text{cluster}} = \frac{T_{\text{slot}}}{T_{\text{cycle}}} \times \sum_{b^{(c)} \in \mathcal{B}_c} \sum_{t \in \mathcal{T}_{\text{tx}}} P_{\text{tx}}(\rho_{b,t}^{(c)}) + \underbrace{\frac{T_{\text{slot}}}{T_{\text{cycle}}} \times (T - |\mathcal{T}_{\text{tx}}|) \times P_{\text{nap}}}_{\text{Energy consumption during napping}}, \quad (25)$$

where T_{cycle} and T_{slot} may denote the time length of flickering pattern cycle and that of each time slot, $P_{\text{tx}}(\rho)$ and P_{nap} may be the total power consumption for given traffic load ρ during transmit mode slot and the power consumption during nap mode slot, respectively, which will be described in more detail below.

[00117] In the following, a total power consumption model according to various embodiments will be described. A realistic total power consumption model of the BS will be described. The RF transmit power may be expressed as a function of the traffic load ρ by slightly modifying the model as

$$P_{\text{RF}}(\rho) = m \times \rho + P_{\text{over}} \kappa(\rho), \quad (26)$$

where m may be the predetermined transmit power per RB and $P_{\text{over}} = p_{\text{over}} \times P_{\text{max}}$ may be the fixed overhead of the radiated power related to, e.g., reference signal (RS) and

$$\kappa(\rho) = \begin{cases} 1 & \text{if } \rho > 0 \\ 0 & \text{otherwise} \end{cases} \quad (27)$$

[00118] Since the maximum transmit power may be given as $P_{\max} = m + P_{\text{over}}$, the following equation may hold:

$$P_{\text{RF}}(\rho) = (P_{\max} - P_{\text{over}}) \times \rho + P_{\text{over}} \kappa(\rho). \quad (28)$$

[00119] The following equation may express the drain efficiency (output RF power to required DC power) of a Doherty amplifier:

$$\eta(P_{\text{RF}}(\rho)) = \begin{cases} \left(\frac{\pi}{2}\right) \times \sqrt{k P_{\text{RF}}(\rho)} & 0 < k P_{\text{RF}}(\rho) < \frac{1}{4} \\ \left(\frac{\pi}{2}\right) \times \frac{k P_{\text{RF}}(\rho)}{3\sqrt{k P_{\text{RF}}(\rho)} - 1} & \frac{1}{4} \leq k P_{\text{RF}}(\rho) \leq 1 \end{cases}, \quad (29)$$

where, $k = 1/(P_{\max} \times 10^{\text{OBO}/10})$ i.e., the inverse of the peak output power. Since the peak-to-average power ratio (PAPR) of a cellular system using orthogonal frequency division multiplexing (OFDM) may generally be larger than 6 dB, output backoff (OBO) may be set to more than 6 dB. Hence, the drain efficiency may always be determined by using the upper equation of equation (29).

[00120] Let us denote the amplification gain of the PA by g , i.e., $P_{\text{RF}} = g P_{\text{in}}$ with P_{in} denoting the input drive power to PA. Then, the total required power of the PA may be obtained as

$$P_{\text{PA}}(\rho) = P_{\text{DC}} + P_{\text{in}} = \frac{P_{\text{RF}}(\rho)}{\eta(P_{\text{RF}}(\rho))} + \frac{P_{\text{RF}}(\rho)}{g} = \left(\frac{1}{\eta(P_{\text{RF}}(\rho))} + \frac{1}{g} \right) \times P_{\text{RF}}(\rho). \quad (30)$$

[00121] The total power consumption of BS for given traffic load ρ may be given as

$$P_{\text{tx}}(\rho) = \left(P_{\text{fix}} + \rho \times P_{\text{dyn}} + \underbrace{\frac{1}{g} P_{\text{RF}}(\rho) + \frac{2}{\pi\sqrt{k}} \sqrt{P_{\text{RF}}(\rho)}}_{P_{\text{PA}}(\rho)} \right) \times P_{\text{loss}}, \quad (31)$$

where P_{fix} and P_{dyn} may denote the power consumption at small-signal RF transceiver and that at base band interface, respectively, and P_{loss} may be the total power loss due to AC-DC (alternating current – direct current) and DC-DC (direct current – direct current) converters loss and cooling. Each value of the consumed power is shown in Table 1.

Power amplifier (PA)			P_{PA}
Small-signal RF transceiver	Tx	5.7 (W)	P_{fix}
	Rx	5.1 (W)	
Baseband Interface (BB)		14.8 (W)	P_{dyn}
DC-DC converter loss		6.4 (%)	P_{loss}
Cooling loss		10.0 (%)	
AC-DC converter loss		7.2 (%)	

Table 1: Breakdown of fixed and dynamic power consumption of BS

[00122] The total power consumption of BS during unallocated time slot may be given as

$$P_{\text{nap}} = P_{\text{tx}}(0) = P_{\text{fix}} \times P_{\text{loss}}. \quad (32)$$

[00123] An example of power consumptions of the commonly used system and the proposed system are shown in FIGS. 13A and 13B.

[00124] FIG. 13A show a diagram 1300 illustrating energy consumption of a commonly used system with non-slotted transmission.

[00125] FIG. 13B show a diagram 1350 illustrating energy consumption of a system with slot based transmission according to various embodiments.

[00126] In the following, simulation results of the devices and methods according to various embodiments under realistic environment will be described.

[00127] The energy consumption of the strategy according to various embodiments may be evaluated. The simulation parameters may be as summarized in Table 2.

Cell layout	Cluster size	B	1 (commonly used), 3, 4, 7, 9
	Cell radius	r_{cell}	290 (m)
	Overlapping area	r_{over}	80 (m)
System parameters	Total bandwidth	W_{total}	10 (MHz)
	Frequency reuse factor	FRF	1
	Number of RBs	M	50
	Number of users	U	1~30 per BS
	Number of receive antennas at user		2
	Maximum transmit power	P_{max}	46 (dBm)
	Overhead	p_{over}	0.1
	Output backoff (OBO)	OBO	8 (dB)
	SINR threshold	γ^{th}	-5 (dB)
Flickering	Flickering pattern cycle	T	3
	Flickering pattern matrix	$\mathbf{F}$	Orthogonal(14)
	Mapping matrix	$\mathbf{M}$	Fixed mapping(15)

Scheduler	Frequency domain user scheduling		Round Robin (RR)
	RB allocation for each user		Random
Antenna configuration	HPBW for vertical beam	ψ_{3dB}	10 (degrees)
	Horizontal sidelobe floor	A_v	20 (dB)
	Electrical antenna down tilt	ψ_{etilt}	15 (degrees)
	BS height		32 (m)
	User height		1.5 (m)
Channel model	Distance dependant path loss	$PL_{u,b^{(c)}}$	$128.1 + 37.6 \log_{10} d_{u,b^{(c)}} (m)$
	Shadowing standard deviation	σ	8 (dB)
	AWGN power density		-174 (dBm/Hz)

Table 2 Simulation parameters.

[00128] It will be understood that the time slot based transmission with flickering pattern matrix according to various embodiments may be combined with arbitrary frequency reuse factor.

[00129] FIG. 14 shows a cluster layout 1400 according to various embodiments in the simulation with $K=3$, wherein two clusters 1402 and 1404 are exemplarily provided with reference signs.

[00130] Each user may be assumed to be equipped with two receive antennas. U users may be uniformly and randomly distributed within each cell as shown in FIG. 14 and the interference from neighbouring six clusters may be taken into account. Another user may be generated again if the calculated SINR is less than the threshold as

$$\max_{b^{(c)} \in \mathcal{B}_c, t \in \mathcal{T}_{\text{tx}}} \gamma_{u, (b^{(c)}, t)} < \gamma^{\text{th}}. \quad (33)$$

where γ^{th} may be the predetermined threshold.

[00131] The distance dependent path loss may be calculated as

$$PL_{u, b^{(c)}} = 128.1 + 37.6 \log_{10} d_{u, b^{(c)}}, \quad (34)$$

where $d_{u, b^{(c)}}$ may be the distance between user u and BS b in cluster c in (m).

[00132] Antenna gain $A(\psi_{u, b^{(c)}})$ may be given as

$$A(\psi_{u, b^{(c)}}) = -\min \left[G_v(\psi_{u, b^{(c)}}), A_v \right], \quad (35)$$

where $G_v(\psi_{u, b^{(c)}})$ may denote the vertical antenna radiation pattern, which may be given as

$$G_v(\psi_{u, b^{(c)}}) = -\min \left[12 \times \left(\frac{\psi_{u, b^{(c)}} - \psi_{\text{etilt}}}{\psi_{3\text{dB}}} \right)^2, A_v \right], \quad (36)$$

where $\psi_{u, b^{(c)}}$ may be the elevation angle of user u from the main-beam direction of the antenna of BS b , $\psi_{3\text{dB}}$ may be the half power beamwidth (HPBW) for the vertical beam pattern, ψ_{etilt} may be the electrical antenna down tilt (positive value), and A_v may be the sidelobe floor.

[00133] FIG. 15A shows a diagram 1500, FIG. 15B a diagram 1502, and FIG. 15C a diagram 1504 illustrating the average energy consumption per each BS, average blocking probability, and average traffic load per BS during the allocated time slot of the strategy, i.e., $E^{BS} = E^{\text{cluster}} / B$, according to various embodiments with the cluster size B being parameterized.

[00134] FIGS. 15A, 15B and 15C, show a diagram illustrating a performance of the time slot based transmission according to various embodiments with $U=10$: FIG. 15A illustrates an average energy consumption per BS during allocated time slot (J); FIG. 15B illustrates an average blocking probability; and FIG. 15C illustrates an average traffic load per BS per allocated time slot.

[00135] The number of users per cell may be set to $U=10$. When $B=1$, the strategy according to various embodiments may degenerate into the commonly used system. FIG. 15A clearly shows that significant amount of energy saving may be achieved by the proposed approach. The energy saving gain may become larger as the cluster size B increases due to the less intra-cluster and inter-cluster interferences. However, the blocking probability of the system may become higher due to the shorter transmission duration as shown in FIG. 15B. This is also supported by FIG. 15C as the traffic load of each BS during the allocated time slot becomes higher as the target rate becomes higher.

[00136] FIG. 16A, FIG. 16B, and FIG. 16C illustrate the impact of the number of users U when the target rate is fixed to $R^{\text{tar}}=1$ (Mbps). FIG. 16A shows a diagram 1600 illustrating an average energy consumption per BS during allocated time slot (J); FIG. 16B shows a diagram 1602 illustrating an average blocking probability; and FIG. 16C shows a diagram 1604 illustrating an average traffic load per BS per allocated time slot.

[00137] FIG. 16A clearly shows that the approach according to various embodiments may provide significant amount of energy saving gain for whole range of the number of users. However, the blocking probability may be severely degraded when the cluster size becomes larger due to shorter transmission duration for each BS. When the cluster size is set to $B=3$, significant amount of energy saving up to 50% saving may be achieved while the increase of the blocking probability is negligible. From FIG. 16B, it can be seen that the blocking probability of the proposed system with $B=7$ and 9 is high. This may be because the available frequency domain RBs are not enough as the traffic load approaches 1 as shown in FIG. 16C.

[00138] According to various embodiments, devices and method may be provided for a time slot based transmission with flickering pattern matrix and mapping matrix, which may realize the fractional time reuse (FTR) strategy, which may significantly reduce the energy consumption of cellular communication system compared to the non-slotted system. The devices and methods according to various embodiments do not need any complex cooperation among the BSs such as data sharing and exchange of CSI (channel state information), hence they may be of low complexity and may significantly reduce the requirement for backhaul network.

[00139] According to various embodiments, a fractional time reuse (FTR) strategy for wireless networks may be provided, where a fraction of transmitters (TXs) are transmitting at each time.

[00140] According to various embodiments, a non-transmitting adaptive protocol (NAP) to realize the FTR strategy may be provided. A TX with NAP may switch its

mode, i.e., transmit mode or nap mode in each time slot. The BS using the NAP may be called as a flickering BS.

[00141] According to various embodiments, the flickering pattern may repeat at each flickering pattern cycle, which may be arbitrarily determined according to the system requirement and affordable complexity.

[00142] According to various embodiments, a general flickering pattern matrix F_G (Eq. (2)) which may include orthogonal flickering pattern matrix and random pattern matrix may be provided.

[00143] According to various embodiments, a general mapping matrix M (Eq. (6)) which may include fixed mapping and/ or random mapping, may be provided.

[00144] According to various embodiments, a general flickering pattern matrix and a general mapping matrix may be any binary matrix.

[00145] According to various embodiments, clustering of BSs including regular shape and irregular shape may be provided.

[00146] According to various embodiments, an orthogonal flickering pattern matrix and/ or a fixed mapping matrix to completely eliminate the intra-cluster interference and reduce the inter-cluster interference (like described with reference to Eq. (19) and to FIG. 12) may be provided.

[00147] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is

thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

What is claimed is:

1. A method for determining an activation scheme of a radio communication device, the method comprising:

determining a plurality of frames according to a multiple access scheme; and

determining for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication.
2. The method of claim 1, further comprising:

grouping a plurality of radio communication devices including the radio communication device to a cluster;

coordinating the determining of the first portion of the frame and the second portion of the frame based on an implicit coordination in the cluster.
3. The method of claim 1, further comprising:

the radio communication device transmitting information indicating its load status to a decision device; and

the decision device determining the first portion of the frame and the second portion of the frame based on the information transmitted by the radio communication device.

4. The method of claim 1,
wherein the decision device determines the first portion of the frame and the second portion of the frame based on a criterion on at least one of a communication condition of the radio communication device or current traffic load within a cluster.
5. The method of claim 1, further comprising:
the radio communication device determining during which portions of a frame the neighbouring radio communication device is to perform communication, and during which portions of the frame during the neighbouring radio communication device is to not perform communication.
6. The method of claim 1,
wherein the multiple access scheme comprises at least one multiple access scheme selected from a list of multiple access schemes consisting of:
a frequency-division multiple access (FDMA) scheme;
a wavelength division multiple access (WDMA) scheme;
an orthogonal frequency-division multiple access (OFDMA) scheme;
a single-carrier FDMA (SC-FDMA) scheme;
a linearly-precoded OFDMA (LP-OFDMA) scheme;
a single-carrier frequency-domain-equalization (SC-FDE) access scheme;
a time-division multiple access (TDMA) scheme;

a multi-frequency time division multiple access (MF-TDMA) scheme;

a code division multiple access (CDMA) scheme;

a spread spectrum multiple access (SSMA) scheme;

a direct-sequence CDMA (DS-CDMA) scheme;

a direct-sequence spread spectrum (DSSS) scheme;

a frequency-hopping CDMA (FH-CDMA) scheme;

a Frequency-hopping spread spectrum (FHSS) scheme;

an orthogonal frequency-hopping multiple access (OFHMA) scheme;

a multi-carrier code division multiple access (MC-CDMA) scheme;

a space division multiple access (SDMA) scheme;

an Aloha scheme;

a Slotted Aloha scheme;

a multiple access with collision avoidance (MACA) scheme;

a multiple access with collision avoidance for wireless (MACAW) scheme;

a carrier sense multiple access (CSMA) scheme;

a carrier sense multiple access with collision detection (CSMA/CD) scheme;

a carrier sense multiple access with collision avoidance (CSMA/CA) scheme;

a distributed coordination function (DCF) scheme;

a carrier sense multiple access with collision avoidance and resolution using Priorities (CSMA/CARP) scheme;

a carrier sense multiple access/bitwise arbitration (CSMA/BA) scheme;

a token ring scheme;

a token bus scheme;

a polling scheme;
a resource reservation (scheduled) packet-mode protocol scheme;
a dynamic time division multiple access (Dynamic TDMA) scheme;
a packet reservation multiple access (PRMA) scheme; and
a reservation ALOHA (R-ALOHA) scheme.

7. The method of claim 1,
wherein determining for each frame of the plurality of frames a first portion of the frame, during which the radio communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication, comprises determining a flickering matrix indicating which of a plurality of base stations including the base station performs communication during which portion of the frame.
8. The method of claim 1,
wherein determining the flickering matrix comprises determining a general flickering pattern matrix comprising indications of possible communication status for various portions of the frame.
9. The method of claim 8,
wherein determining the flickering matrix further comprises determining a mapping matrix comprising indications of which possible communication status from the general flickering pattern matrix are to be selected.

10. The method of claim 1,
wherein each frame is divided into a plurality of slots;
wherein the first portion of the frame comprises a first subset of the slots; and
wherein the second portion of the frame comprises a second subset of the slots.
11. The method of claim 1, further comprising:
determining for each frame of the plurality of frames a first portion of the frame,
during which the radio communication device performs communication, and a
second portion of the frame during which the radio communication device does
not perform communication, based on at least one of a communication condition
of the radio communication device or current traffic load within a cluster.
12. The method of claim 11,
wherein the communication condition comprises at least one of a quality of
service requirement of the radio communication device or a bandwidth
requirement of the radio communication device.
13. A radio communication device comprising:
a frame determination circuit configured to determine a plurality of frames
according to a multiple access scheme; and
an activation scheme determination circuit configured to determine for each frame
of the plurality of frames a first portion of the frame, during which the radio

communication device performs communication, and a second portion of the frame during which the radio communication device does not perform communication.

14. The radio communication device of claim 13,
wherein the activation scheme determination circuit is further configured to coordinate the determining of the first portion of the frame and the second portion of the frame based on an implicit coordination in a cluster including the radio communication device and a plurality of further radio communication devices.
15. The radio communication device of claim 13, further comprising:
a transmitter configured to transmitting information indicating a load status of the radio communication device to a decision device.
16. The radio communication device of claim 13, further comprising:
a neighbouring base station state determiner configured to determining during which portions of a frame the neighbouring radio communication device is to perform communication, and during which portions of the frame during the neighbouring radio communication device is to not perform communication.
17. A radio communication device comprising:

a communication circuit configured to communicate with another radio communication device based on a frame structure comprising a plurality of communication frames;

wherein in each communication frame of the plurality of communication frames, the communication circuit is configured to be active in a pre-determined first portion of the communication frame and to be de-activated in a pre-determined second portion of the communication frame.

18. A decision device comprising:

a grouping circuit configured to group a plurality of radio communication devices including the radio communication device to a cluster;

a coordination circuit configured to determine for each frame according to a multiple access scheme a first portion of the frame, during which a radio communication device is allowed to perform communication, and a second portion of the frame during which the radio communication device is not allowed to perform communication.

19. The decision device of claim 18, further comprising:

a receiver configured to receive from the radio communication device information indicating the load status of the radio communication device; and

wherein the coordination circuit is further configured to determine the first portion of the frame and the second portion of the frame based on the information transmitted by the radio communication device.

20. The decision device of claim 18,
wherein the coordination circuit is further configured to determine the first portion of the frame and the second portion of the frame based on a criterion on at least one of a communication condition of the radio communication device or current traffic load within a cluster.