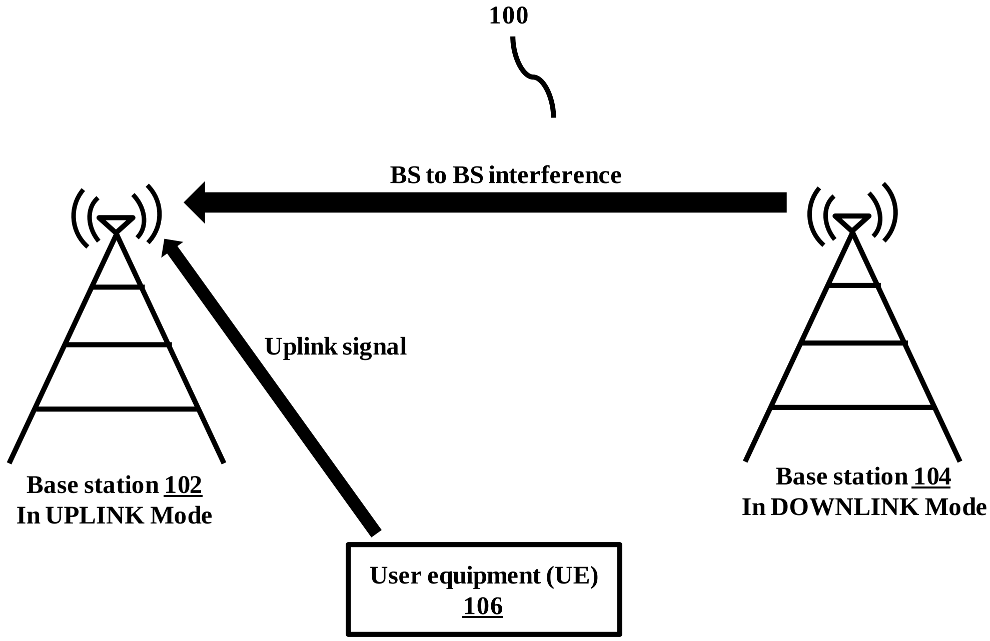

FIG. 1

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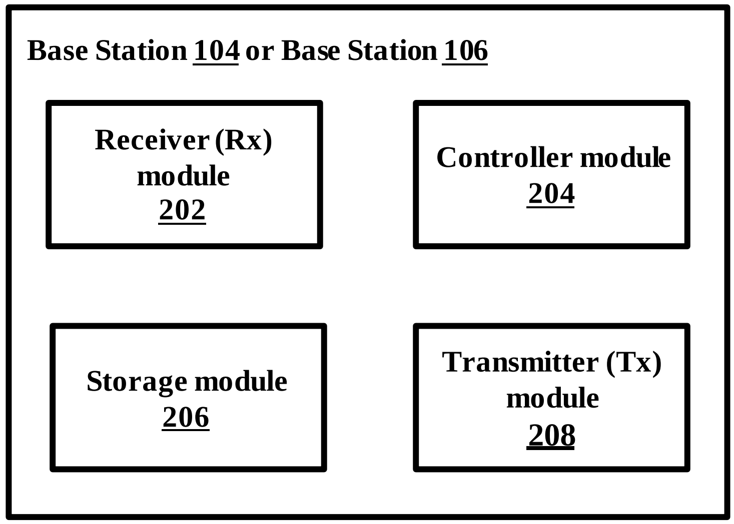

FIG. 2

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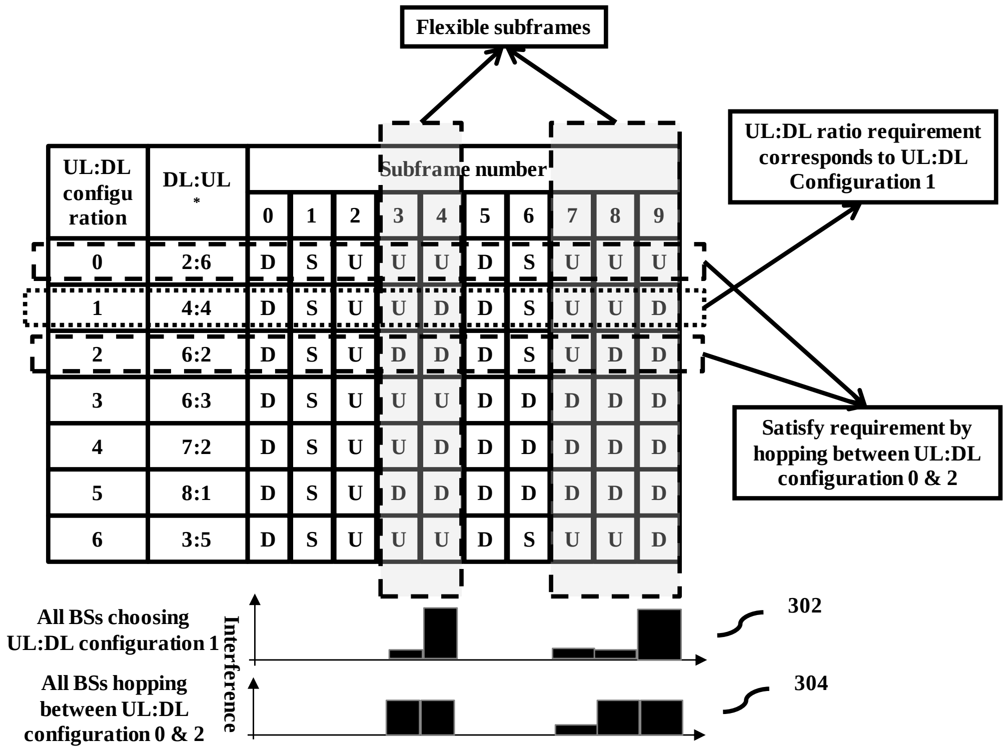

UL:DL configuration	DL:UL *	0	1	2	3	4	5	6	7	8	9
		Subframe number									
0	2:6	D	S	U	U	U	D	S	U	U	U
1	4:4	D	S	U	U	D	D	S	U	U	D
2	6:2	D	S	U	D	D	D	S	U	D	D
3	6:3	D	S	U	U	U	D	D	D	D	D
4	7:2	D	S	U	U	D	D	D	D	D	D
5	8:1	D	S	U	D	D	D	D	D	D	D
6	3:5	D	S	U	U	U	D	S	U	U	D

FIG. 3

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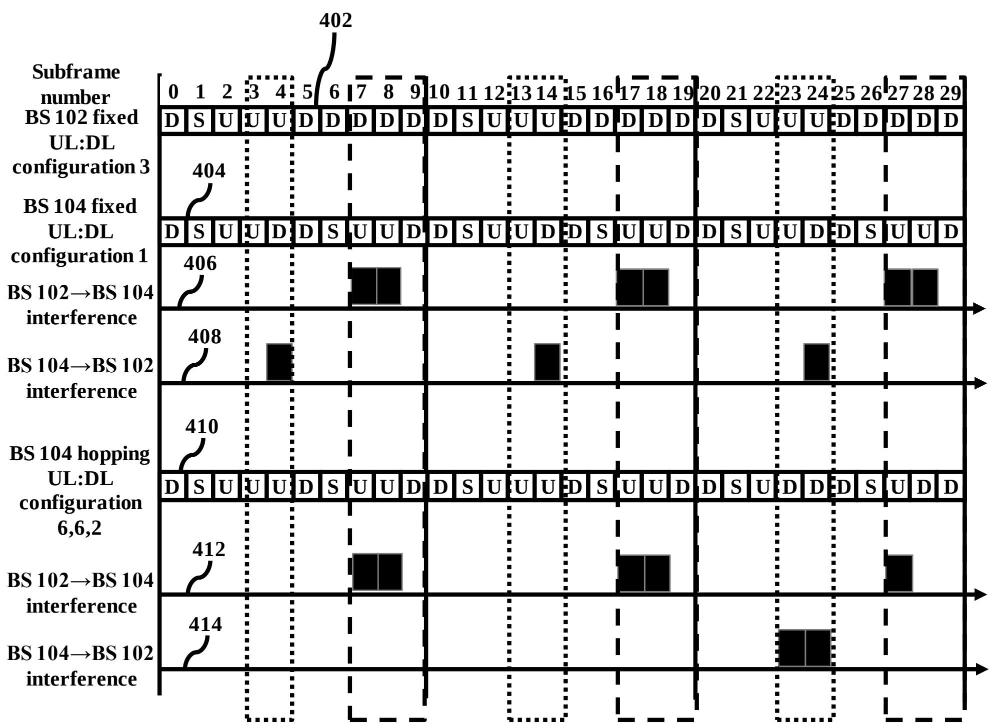

FIG. 4

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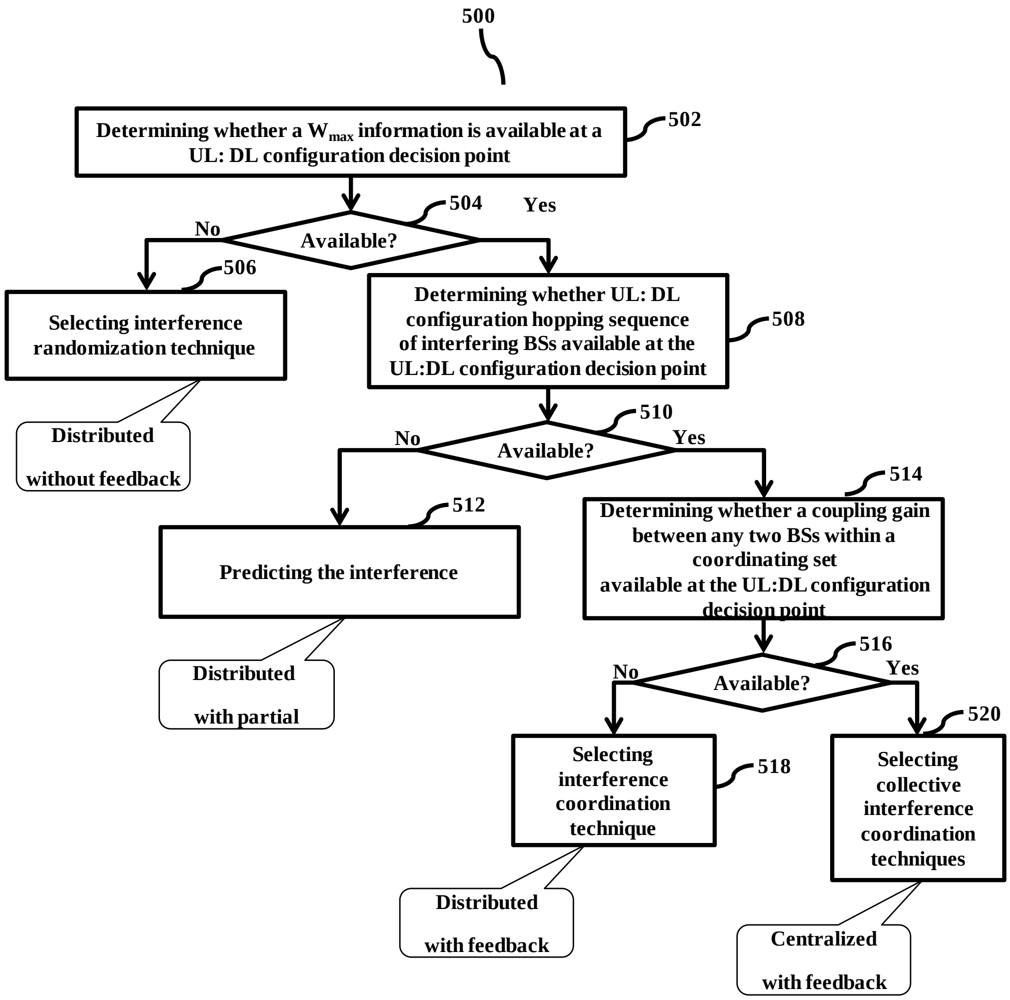

FIG. 5

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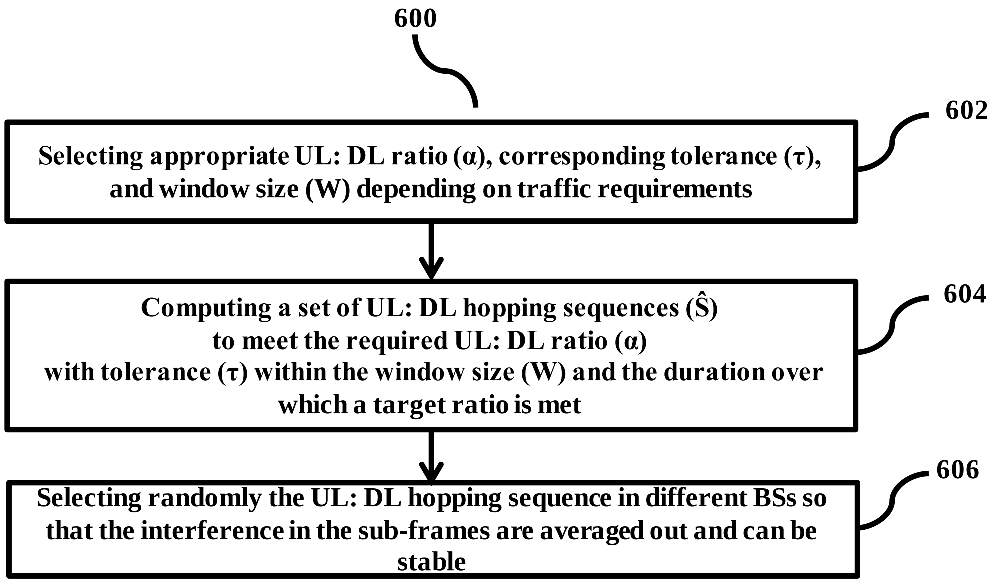

FIG. 6

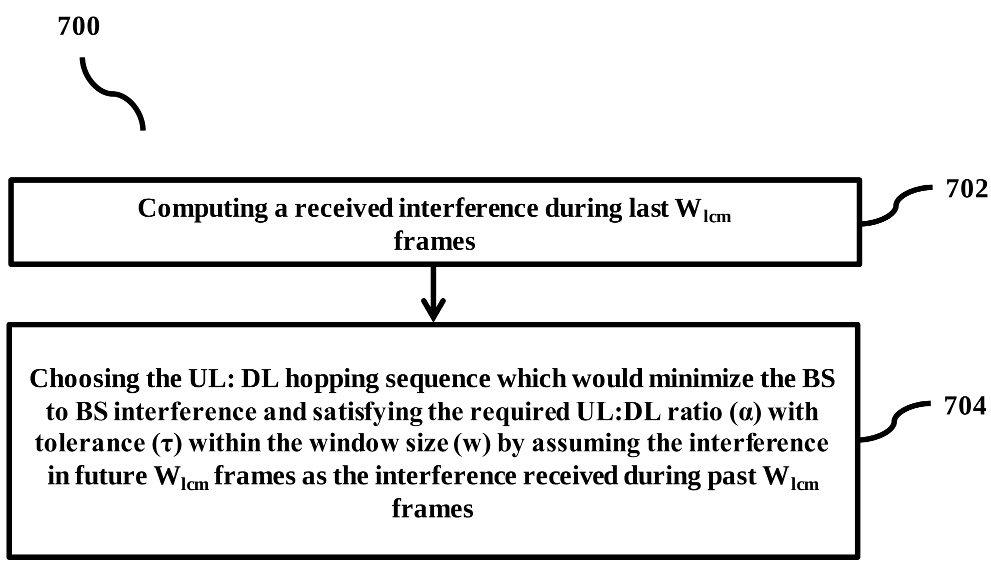

FIG. 7

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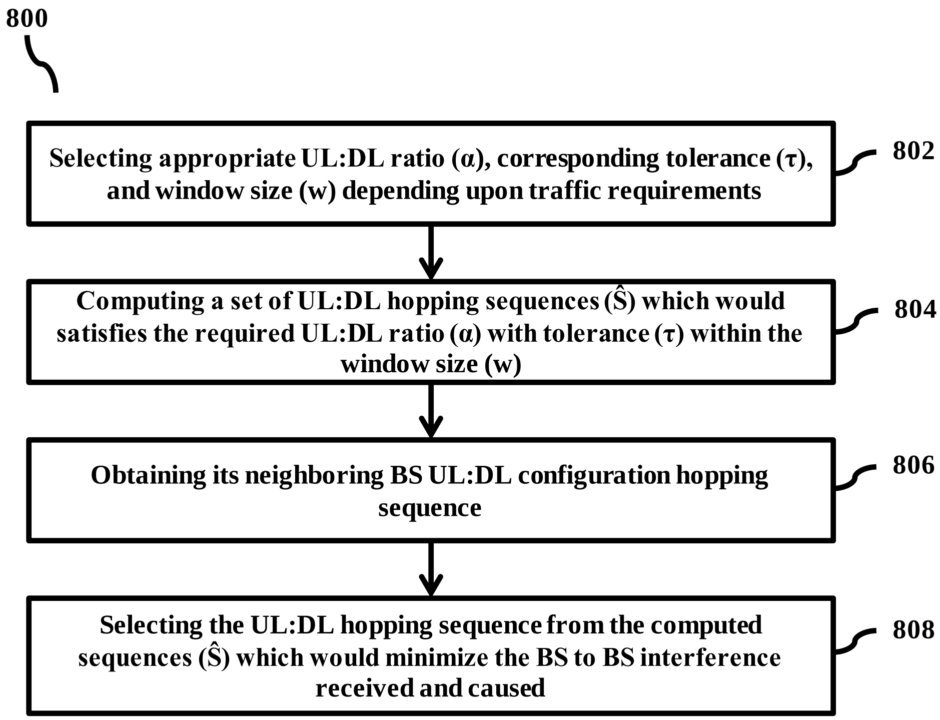

FIG. 8

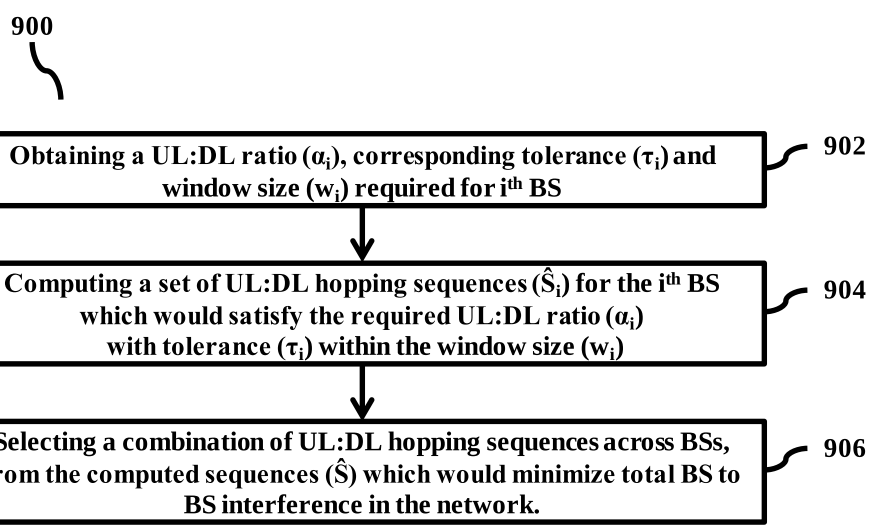

FIG. 9

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TECHNICAL FIELD

[001] The Invention herein relate to communication systems and, more particularly, to uplink-downlink configuration hopping for interference mitigation in communication systems.

BACKGROUND

[002] Inter-cell and intra-cell interference in a cellular system can be managed at the BS (an eNode-B or transmission point in long term evolution (LTE) is also a BS) level either by interference randomization or interference coordination. A BS can be a macro or a pico or a remote radio head (RRH) end. Cellular networks has already been using popular interference randomization techniques like applying pseudo random scrambling after channel coding/interleaving or frequency hopping or spreading or distributed allocation of resource in LTE sub frames. Some of the above schemes are specific to a cell depending on their cell ID or any other cell identifiers so that strong interferers in the system are averaged producing only less or tolerable impact on adjacent cell users.

[003] Also, it is a well known fact that interference randomization is an efficient technique when there is no information about the source and/or nature of the interference. Similarly, when there is partial or full information about the source and/or nature of interference, coordination or a mix of

randomization and coordination techniques can be used to mitigate the interference by making appropriate decisions at every BS in a distributed manner or at every group of BS in a centralized manner.

[004] Traditionally, cellular networks have more or less stable asymmetric traffic with more DL than the UL data, and TDD with more DL is the preferred configuration. However, due to the advent of the social media, and other applications like video conferencing etc., the current DL traffic can be greater than or equal to or less than the UL traffic, and is different across bases stations, and moreover, it varies dynamically over time. Therefore, using same UL: DL configurations across all the cells will result in less efficient usage of resources. Hence it will be more appropriate to configure different UL:DL configurations in different BSs based on the traffic requirement in the corresponding cell and is adapted over time based on the instantaneous traffic requirements.

[005] For example, LTE, support 7 UL: DL configurations to provide different UL and DL for different traffic requirements in the UL and DL, respectively. A LTE system has a 10 msec radio frame consisting of 10 subframes in which, certain sub frames remain fixed as DL or UL or special-subframe (SF) irrespective of configuration, while the remaining subframes alternate between DL or UL according to the configuration.

[006] Normally, the standards support only a limited set of UL:DL configurations to meet the traffic requirements in order to minimize the signaling overhead. This limits the choice of UL: DL ratio only to the standards supported set of UL: DL configurations. Also, operating simultaneously with different UL: DL configuration in different BSs can cause severe BS to BS or user to user interference in the network resulting in very high interference in certain subframes depending on the interfering BS or user locations and distance. Dynamic UL:DL configuration adaptation based on traffic requirement make the problem even worse due to the fact that this interference is highly fluctuating, resulting in an unstable channel quality indicator (CQI) or power control feedback so that the feedback data may not be useful.

BRIEF DESCRIPTION OF THE FIGURES

[007] The Invention herein will be better understood from the following detailed description with reference to the drawings, in which:

[008] FIG. 1 illustrates an example of interference randomization, as disclosed in the Invention herein;

[009] FIG. 2 illustrates an example of interference randomization, as disclosed in the Invention herein;

[0010] Figure 3 is the flow chart showing the algorithm selection based upon available feedback information, as disclosed in the Invention herein;

[0011] Figure 4 is the flow chart showing interference randomization when no feedback information is available, as disclosed in the Invention herein;

[0012] Figure 5 is the flow chart showing interference coordination when partial feedback information is available in each base station, as disclosed in the Invention herein; and

[0013] Figure 6 is the flow chart showing collective coordination of interference when full feedback information is available at each base station/network controller, as disclosed in the Invention herein.

DETAILED DESCRIPTION OF INVENTION

[0014] The Invention herein and the various features and advantageous details thereof are explained more fully with reference to the non-limiting Invention that are illustrated in the accompanying drawings and detailed in the following description. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the Invention herein. The examples used herein are intended merely to facilitate an understanding of ways in which the Invention herein may be practiced and to further enable those of skill in the art to practice the Invention herein. Accordingly, the examples should not be construed as limiting the scope of the Invention herein.

[0015] The present invention is directed at achieving finer UL: DL traffic adaptation over time using the combinations of configuration that has signaling support as specified in the standards, and/or simultaneously mitigating the effect of interference in the network either by randomizing the interference or by coordinating between BS for the above mentioned problem in a generalized manner. A UL: DL hopping sequence is a set of UL: DL configurations applied over a set of frames. Forming a hopping sequence by combining UL: DL configurations also help to achieve any required UL: DL ratio target that might not be supported by the standards already.

[0016] In a preferred embodiment, every BS in the network estimates its traffic asymmetry requirement, and achieves this ratio by appropriate choice of UL: DL configurations instantaneously or combination of configurations that are already specified or may be newly added in the standards over time. The combination is obtained, for example, based on the frame duration in which the UL: DL ratio target must be met and/or the finer accuracy of the UL: DL ratio.

[0017] In another embodiment, the configuration is hopped on a frame basis, and is obtained from a predetermined set or it is chosen independently in every BS in a proprietary manner or in a coordinating manner among the BSs depending on the time duration over which the UL: DL ratio target has to be met and/or the finer accuracy of the UL: DL ratio. The choice of configuration during a particular instant is chosen randomly from the entries of a predetermined set with any entry in the set chosen once with or without using a cell specific permutation.

[0018] In yet another embodiment, a set of configuration is hopped on a group of frames basis, and is obtained from the predetermined sets or it is chosen independently in every BS in a proprietary manner or in a coordinating manner among the BSs depending on the time duration over which the UL: DL ratio target is met and/or the finer accuracy of the UL: DL ratio. The choice of the set of configurations for the time duration over which the UL: DL ratio target has to be met is chosen randomly from the predetermined sets with any set chosen only once with or without using a cell specific permutation. Sample combinations of configuration to obtain the hopping sequence for the configurations specified in LTE are shown in TABLE 1.

[0019] Interference mitigation by a BS is proposed for the following three scenarios:

- When no information about UL:DL configuration used in other BSs is available
- When information about UL:DL configuration used in other BSs alone is available
- When UL: DL configurations used by all BSs, and additional information about other BSs in the network are made available by using backhaul support to exchange information between BSs.

Scenario 1

[0020] In this scenario, there is no information about UL: DL configuration used in other BSs is available, so every BS can independently decide on the hopping sequence to meet the required UL: DL ratio and the duration over which the target ratio is met. This ensures that the UL: DL configuration in different BSs are random so that the interference in the subframes where there is mix of DL and UL transmissions are averaged out, and is stable. Moreover, there may be scenario in which, more than one BS may have same UL: DL ratio target. For effective interference averaging cell specific permutation can be applied. This will also enable a unified power control algorithm with a different power control parameter for the UL transmissions in these subframes. An example is illustrated in Figure 1.

Scenario 2

[0021] In this scenario, information about UL: DL configuration used in other BSs alone is available. Appropriate choice of hopping sequence is chosen based on this information. For example, when the required UL: DL ratio of all the nearby BS are same, then use the same UL: DL configuration as configured in the standards or choose the same combination of UL: DL configuration across all BSs to meet the required UL: DL ratio. When the required UL: DL ratio are different, then choose either UL: DL configuration hopping sequence which would minimize or at least reduce either received interference or caused interference or both at every BS independently or the interference randomization scheme explained in scenario 1. An example is illustrated in Figure 2.

Scenario 3

[0022] In this scenario, additional information like coupling gain between any pair of BSs, the finer accuracy of the UL: DL ratio of all BSs, the time duration over which the required UL: DL ratio needs to be met etc. about other BSs are available. Appropriate choice of hopping sequence is chosen for each BS at a centralized network controller or at individual BSs based on all available information. For example when the required UL: DL ratio of all the nearby BS are same, do interference coordination as mentioned in scenario 2. When the required UL: DL ratio are different, choose a combination of sets in such a way that the subframes are aligned for as many subframes as it can, and choose UL: DL configuration hopping sequence in such a way that the overall interference in the network is minimized or at least reduced. If the above solutions are nonexistent, then perform interference randomization scheme as explained in scenario 1.

[0023] Proper care should also be taken that the length of the hopping sequence chosen to achieve a required UL: DL ratio is sufficiently small enough to achieve the required UL: DL ratio (α) within a window size (w), as chosen or learned by the network to follow the dynamic change in the traffic load at each BS, where w is the number of frames required to meet α.

[0024] A tolerance variable (τ) lying in the interval [0,1] will help in achieving a target UL:DL ratio much closer to the required UL:DL ratio. A BS/radio-network-controller would compute hopping sequence that would provide a UL: DL ratio within the tolerance interval $[(1-\tau)\ \alpha, (1+\tau)\ \alpha]$, within required window size w. The value τ will provide tradeoff between target UL: DL ratio (α) and interference mitigation for the explained scenarios 1 to 3. For τ closer to 1, interference mitigation is better due to the possibility of having more number of hopping sequences, however, the achieved overall UL:DL ratio may not be closer to α. Similarly τ closer to 0, provides UL:DL ratio closer to α, with less number of hopping sequences, which may result in more interference in the network. If there is no hopping sequence which would provide the desired α within the tolerance interval and desired window size, then a hopping sequence achieving a target UL:DL ratio closer to the α is chosen.

Implementation of the above schemes in Practical situations in a LTE system for illustration purpose:

[0025] TABLE 1 provides the UL:DL ratio of different UL:DL configuration as specified in the LTE standard. The table also provides with few sample hopping sequences for each UL: DL configuration with window size of 2 or 3 or 4 frames. Similar hopping sequence design can be made and used for other possible TDD OFDM wireless communication systems.

TABLE 1: Example hopping sequence for various UL:DL configurations in LTE

UL:DL configuration	UL:DL ratio excluding	Hopping sequences

	special subframes	
0	6:2	
1	4:4	(0,2) (hopping sequence 1) (2,6,6) (hopping sequence 2)
2	2:6	(3,3,4,5)
3	3:6	(1,2,2)
4	2:7	(3,5)
5	1:8	
6	5:3	(0,1)

[0026] Any UL: DL ratio other than the one specified in standards can also be achieved by combining different UL: DL configurations. For example a ratio of 1:5 can be obtained by forming a hopping sequence of UL: DL configuration (4, 5). Similarly for 2:3 by hopping sequence (1, 5, 6). This provides the flexibility to achieve any UL: DL ratio corresponding to a traffic load requirement not available in the specified set of UL: DL configurations in LTE.

TABLE 2: Sample hopping sequence for various UL:DL configurations in LTE with 5ms periodicity of Special Subframes

UL:DL configuration	UL:DL ratio excluding special subframes	Hopping sequences
0	6:2	
1	4:4	(0,2)
2	2:6	
6	5:3	(0,1)

TABLE 3: Sample hopping sequence for various UL:DL configurations in LTE with 10ms periodicity of Special Subframes

UL:DL Configuration	UL:DL ratio excluding special subframes	Hopping sequences
3	3:6	
4	2:7	(3,5)
5	1:8	

TABLE 4: The three possible scenarios in Tabular form applicable to a LTE system.

	Algorithm 1 Distributed with no feedback	**Algorithm 2** Distributed with feedback	**Algorithm 3** Centralized with feedback
Usage Scenario	Scenario 1	Scenario 2	Scenario 3
Data exchanged between nodes in the network	No data is exchanged	UL:DL configuration information is available in the BS.	UL:DL configuration, Window size , Tolerance value are available in the BS/network-controller.
Algorithm Details	Interference randomization by randomly choosing a UL:DL configuration hopping sequence which achieves desired UL:DL ratio within the tolerance interval and window size for each	Interference minimization at BS level by picking the best UL: DL configuration hopping sequence which achieves desired UL: DL ratio within the tolerance interval and window size, which	Interference minimization by coordination by picking the best combination of UL: DL configuration hopping sequences among BS which achieves desired UL:

	BS independently.	would mitigate interference for each BS using the feedback information.	DL ratio for each BS and minimizes the total interference of the system.
	Summarized by Figure 4	Summarized by Figure 5	Summarized by Figure 6

COMPUTATION OF INTERFERENCE BETWEEN BSs USING DIFFERENT UL:DL CONFIGURATIONS HOPPING SEQUENCE

[0027] In LTE, the major interference faced by a BS is DL to UL interference, which occurs when a BS is in UL mode, while it's neighboring BS is in DL mode. TABLE 5 provides interference caused by a UL: DL configuration to another UL:DL configuration in terms of number of DL subframes interfering to UL subframes, in a frame.

TABLE 5: Number of DL Subframes interfering to UL Subframes for UL:DL configurations in LTE. (Each row corresponds to UL:DL configuration of interfering BS, and each column corresponds to UL:DL configuration of victim BS)

|	UL:DL-Config_0	UL:DL-Config 1	UL:DL-Config 2	UL:DL-Config 3	UL:DL-Config 4	UL:DL-Config 5	UL:DL-Config 6
UL:DL-Config 0	0	0	0	0	0	0	0
UL:DL-Config 1	2	0	0	1	0	0	1
UL:DL-Config 2	4	2	0	2	1	0	3
UL:DL-Config 3	3	2	1	0	0	0	2

UL:DL-Config 4	4	2	1	1	0	0	3
UL:DL-Config 5	5	3	1	2	1	0	4
UL:DL-Config 6	1	0	0	0	0	0	0

TABLE 6: Number of DL Subframes interfering to UL Subframes for UL:DL configurations with 5ms periodicity of Special Subframes. (Each row corresponds to UL:DL configuration of interfering BS, and each column corresponds to UL:DL configuration of victim BS)

	UL:DL-Config 0	UL:DL-Config 1	UL:DL-Config 2	UL:DL-Config 6
UL:DL-Config 0	0	0	0	0
UL:DL-Config 1	2	0	0	1
UL:DL-Config 2	4	2	0	3
UL:DL-Config 6	1	0	0	0

TABLE 7: Number of DL Subframes interfering to UL Subframes for UL: DL configurations with 10ms periodicity of Special Subframes. (Each row corresponds to UL: DL configuration of interfering BS, and each column corresponds to UL: DL configuration of victim BS)

	UL:DL-Config 3	UL:DL-Config 4	UL:DL-Config 5
UL:DL-Config 3	0	0	0
UL:DL-Config 4	1	0	0
UL:DL-Config 5	2	1	0

[0028] Let I (m,n) be the number of DL subframes interfering to UL subframes by m^{th} UL:DL configuration to n^{th} UL:DL configuration, as specified in TABLE 5, 6 & 7. Let there be totally N BS in the network, and all having same window size w frames. Let $h_{n,i}$ be the UL:DL configuration of nth

BS on i^{th} frame. Let C (m, n) be the coupling gain from m^{th} BS to n^{th} BS, and P (n) be the DL transmission power of nth BS.

[0029] Total interference caused by m^{th} BS to all other BS in the network within the window size w.

$\hat{I}(m)_{caused} = \Sigma n=\{0,1,...N-1\}\ \Sigma i=\{0,1,...w-1\}\ P(m)*C(m,n)*I(h_{m,i},h_{n,i})$ --- (1)

[0030] Total interference received by mth BS from all other BS in the network within the window size w.

$\hat{I}(m)_{received} = \Sigma n=\{0,1,...N-1\}\ \Sigma i=\{0,1,...w-1\}\ P(n)*C(n,m)*I(h_{n,i},h_{m,i})$ --- (2)

[0031] If coupling gain C (m, n) and DL transmission power P (n) is not available then, assume unity for those values in equations (1) and (2).

[0032] In scenario 2, m^{th} BS has to decide it's UL:DL configuration hopping sequence which would satisfy,

1. Required UL: DL ratio within tolerance (τ) limit, within the required window size (w).

2. Minimize the combined interference caused and received by m^{th} BS, whereas

combined interference is,

$\hat{I}(m)_{combined} = \eta * I_{caused} + (1-\eta) * I_{received}$

where η is a trade-off factor between caused interference and received interference whose value lies in the interval [0,1]. A higher value of η implies caused interference is minimized at the expense of high received interference. A BS has to get/compute η based upon the quality of service dictated by the interference requirement of the network.

[0033] In scenario 3, network-controller/BS has to decide UL:DL configuration hopping sequence of m^{th} BS, which would satisfy ,

- Required UL: DL ratio within tolerance (τ) limit, and within the required window size (w).
- Minimize the sum of combined interferences of all BSs in the network, which is,

[0034] In all scenarios, when DL to UL interfering subframes is minimized, it in turns also minimize UL to DL interfering subframes between neighboring UEs in adjacent cells.

[0035] The Invention herein disclose a method for interference mitigation in a communication network by using uplink-downlink configuration hopping. Referring now to the drawings, and more particularly to FIGS. 1 through 6, where similar reference characters denote corresponding features consistently throughout the figures, there are shown Invention.

[0036] FIG. 1 illustrates an example of interference randomization, as disclosed in the Invention herein. Shaded area represents flexible subframes, in which transmission direction is different for different UL: DL configurations.

A BS requires a UL: DL ratio, which can be satisfied by UL: DL configuration 1. According to existing art, the BS uses a fixed UL: DL configuration 1 alone, which would result in high interference on subframes 4 & 9 (100) on all frames. With present invention, the BS can switch between UL: DL configuration 0 & 2 on alternative subframes and achieve the same UL: DL ratio requirement. If this randomization is done on every BSs in the network with the same UL: DL ratio requirement, then the overall interference caused by these BSs in the network would be equalized over subframes 3,4,8 & 9.

[0037] FIG. 2 illustrates an example of interference randomization, as disclosed in the Invention herein. In this example, 100 and 101 shows fixed UL: DL configurations of 3 and 1 chosen by BS 1 & BS 2 in existing art. In this case BS 2 is receiving high interference from BS 1 on subframes 7,8,17,18,27 & 28 (102). Also BS 2 is causing heavy interference to BS 1 on subframes 4,14 & 24 (103). With present invention, BS 2 can switch its UL: DL configuration to 6, 6 and 2 on subsequent frames (104) but still maintains the UL: DL ratio similar to UL: DL config 1 with periodicity of 3 frames. This which would reduce both received interference (105) and caused interference (106).

[0038] Figure 3 is the flow chart showing the algorithm selection based upon available feedback information, as disclosed in the Invention herein. A UL: DL configuration decision point can be either BS or network-controller. If no feedback information is available at the UL: DL configuration decision point, then algorithm 1 is chosen. If partial feedback information is available at the UL: DL configuration decision point, then algorithm 2 is chosen. Partial feedback includes UL: DL configuration of all interfering BSs. If full feedback information is available at the UL: DL configuration decision point, then algorithm 3 is chosen. Full feedback may include, coupling gain between any pair of BSs in the network, window size, Tolerance value, interference trade-off factor and UL: DL configuration of all BSs in the network. The various actions in method 300 may be performed in the order presented, in a different order or simultaneously. Further, in some Invention, some actions listed in FIG. 3 may be omitted.

[0039] Figure 4 is the flow chart showing interference randomization when no feedback information is available, as disclosed in the Invention herein. The BS gets UL: DL ratio requirement of UEs corresponding tolerance and window size. The BS computes all possible hopping sequences for UL: DL configurations which would satisfy the UL: DL ratio requirement within tolerance limit and in window size (w). Then BS randomly chooses a UL: DL configuration hopping sequence from the computed ones. The various actions in method 400 may be performed in the order presented, in a different order or simultaneously. Further, in some Invention, some actions listed in FIG. 4 may be omitted.

[0040] Figure 5 is the flow chart showing interference coordination when partial feedback information is available in each base station, as disclosed in the Invention herein. The BS would get UL: DL configurations and may compute coupling gain of interfering BSs. The BS computes all possible hopping sequences for UL: DL configurations which would satisfy the UL: DL ratio requirement within tolerance limit and in window size. The BS would select the optimum hopping sequence of UL: DL configuration which would reduce received interference and caused interference. The various actions in method 500 may be performed in the order presented, in a different order or simultaneously. Further, in some Invention, some actions listed in FIG. 5 may be omitted.

[0041] Figure 6 is the flow chart showing collective coordination of interference when full feedback information is available at each base station/network controller, as disclosed in the Invention herein. The network-controller/BS would get UL: DL ratio requirement of all BSs in the network. The network-controller/BS also gets the coupling gains between any pair of BSs in the network, window size, and tolerance value and interference trade-off factor. The network-controller/BS computes all possible hopping sequences for UL: DL configurations which would satisfy the UL: DL ratio requirement within tolerance limit and window size for all BSs. The BS/network-controller would select the optimum hopping sequence of UL: DL configuration which would reduce total interference collectively in the network. The various actions in method 600 may be performed in the order presented, in a different order or simultaneously. Further, in some Invention, some actions listed in FIG. 6 may be omitted.

[0042] The Invention disclosed herein can be implemented through at least one software program running on at least one hardware device and performing network management functions to control the network elements. The network elements shown in Fig. X include blocks which can be at least one of a hardware device, or a combination of hardware device and software module.

[0043] The embodiment disclosed herein specifies a system for interference mitigation in a communication network. The mechanism allows interference mitigation in a communication network, providing a system thereof. Therefore, it is understood that the scope of the protection is extended to such a program and in addition to a computer readable means having a message therein, such computer readable storage means contain program code means for implementation of one or more steps of the method, when the program runs on a server or mobile device or any suitable programmable device. The method is implemented in a preferred embodiment through or together with a software program written in e.g. Very high speed integrated circuit Hardware Description Language (VHDL) another programming language, or implemented by one or more VHDL or several software modules being executed on at least one hardware device. The hardware device can be any kind of device which can be programmed including e.g. any kind of computer like a server or a personal computer, or the like, or any combination thereof, e.g. one processor and two FPGAs. The device may also include means which could be e.g. hardware means like e.g. an ASIC, or a combination of hardware and software means, e.g. an ASIC and an FPGA, or at least one microprocessor and at least one memory with software modules located therein. Thus, the means are at least one hardware means and/or at least one software means. The method Invention described herein could be implemented in pure hardware or partly in hardware and partly in software. The device may also include only software means. Alternatively, the invention may be implemented on different hardware devices, e.g. using a plurality of CPUs.

[0044] The foregoing description of the specific Invention will so fully reveal the general nature of the Invention herein that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific Invention without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed Invention. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. Therefore, while the Invention herein have been described in terms of preferred Invention, those skilled in the art will recognize that the Invention herein can be practiced with modification within the spirit and scope of the claims as described herein.

ABSTRACT

A method for randomizing and/or coordinating the interference in a cellular network by dynamically switching or hopping between UL: DL configurations at the base stations (BS) in a OFDM based time division duplex (TDD) system is disclosed. This method includes a way of computing set of UL: DL configuration hopping sequences to achieve any non supported uplink to downlink (UL: DL) ratio using the supported UL: DL configurations to meet the UL and DL traffic requirements of the network. When there is no information available at a BS about the UL: DL configuration of other BSs, a random UL: DL configuration hopping sequence among predefined or computed sets can be adopted by individual BSs so that the interference is randomized. When certain information is available at a BS about other BSs, a combination of hopping sequences can be used among BSs in a distributed/centralized manner for interference coordination/randomization.

FIG. 1

Dated: 27th Sept, 2013 Signature:

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Patent Agent