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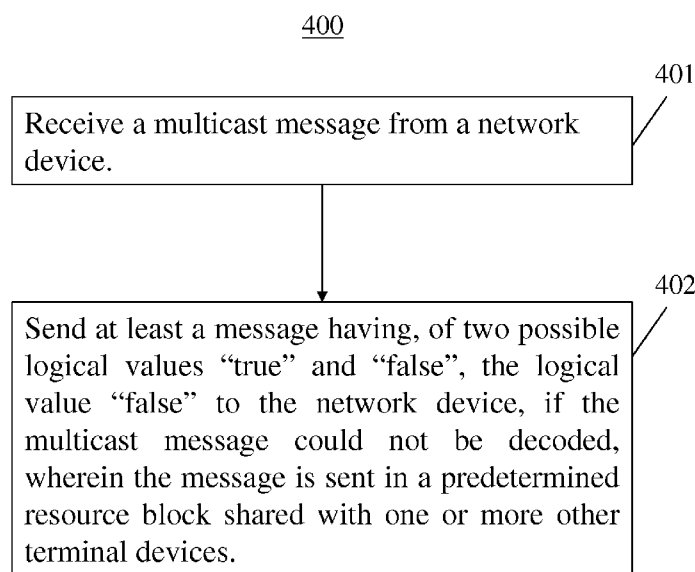


Fig. 4

(57) Abstract: The present invention provides a network device (100), preferably a BS. The network device (100) is configured to receive a signal comprising a plurality of superimposed messages (101), wherein each message (101) is sent by one of a plurality of terminal devices (200) and has one of two possible logical values "true" and "false". The network device (100) is also configured to determine a logical conjunction or disjunction of the superimposed messages (101) based on a comparison of the received signal with a threshold value. Accordingly, the present invention also provides a terminal device (200), preferably a UE. The terminal device (200) is configured to receive a multicast message (201) from a network device (100), and to send at least one message (101) having, of two possible logical values "true" and "false", the logical value "false" to the network device (100), if the terminal device (200) was not able to decode the multicast message (201). Therein, the terminal device (200) is configured to send the message (101) in a predetermined

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NETWORK DEVICE AND TERMINAL DEVICE FOR WIRELESS MULTICAST

TECHNICAL FIELD

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The present invention relates to a network device and to a terminal device, respectively, for implementing an efficient feedback acknowledgment transmission scheme. In particular, a feedback acknowledgement transmission scheme for wireless multicast communication. The present invention also relates to corresponding methods, and to a system including one or more terminal devices and a network device.

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BACKGROUND

In order to achieve a reliable multicast communication, it is essential for a transmitter of a multicast message to learn, whether all intended recipients have received and successfully decoded the multicast message. Currently, this is done by sending individually from each intended receiver either an acknowledgement (ACK) and/or a negative acknowledgement (NACK) to the original transmitter.

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For example, in LTE a 1-bit information defining the ACK or NACK is transmitted in a Physical Hybrid-ARQ Indicator Channel (PHICH) or in a Physical Uplink Control Channel / Physical Uplink Shared Channel (PUCCH/PUSCH) for uplink (UL) and downlink (DL) data transmissions, respectively, in order to indicate the status of the message decoding at the receiver of the multicast message [see e.g. 3GPP TS 36.213].

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The conventional scheme, which is also applied in LTE, is shown in Fig. 6 for a base station (BS) as transmitter of the multicast message, and for a plurality of user equipments (UEs) as receivers of the multicast message. The UEs send in response to the multicast message either the ACK or the NACK, depending on the status of their message decoding, i.e. depending on whether they were able to decode the multicast message or not.

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However, especially when the number of receivers of the multicast message is large (and thus also the number of potentially transmitted ACKs is large), the conventional scheme wastes a lot of wireless resources, because it feeds back a lot more information to the original transmitter

than needed. In particular, all information that the original transmitter in principle needs is, whether or not there was at least one error (indicated by a NACK) in the reception of the multicast message (which typically determines, whether or not the original multicast message needs to be repeated). However, in the conventional scheme the original transmitter has so much information, that it can even exactly reconstruct the number of multicast message recipients, and even which specific receivers could successfully decode the multicast message, and which receivers could not.

In addition to the conventional scheme, there is known a wide range of methods for detecting superimposed signals in a wireless channel. However, the goal of all these methods is reconstructing information encoded by a plurality of transmitters entirely. Thus, these methods are all not suited for solving the above-described problem of wasted resources. Moreover, these methods all use a standard information theoretic approach, in which a transmission rate is to be optimized for a block length tending to infinity. Thus, these methods are all not compatible with the one-bit ACK/NACK information conveyed in the conventional scheme.

SUMMARY

In view of the above-mentioned problems and disadvantages, the present invention aims to improve the conventional scheme of feedback acknowledgment transmissions. The present invention has thereby the object to provide a network device and terminal device, respectively, with which a more efficient, faster, and more reliable scheme can be implemented, particularly for multicast communication.

The object of the present invention is achieved by the solution provided in the enclosed independent claims. Advantageous implementations of the present invention are further defined in the dependent claims.

In particular, the present invention proposes a scheme, in which a joint feedback message is sent in response to a multicast message simultaneously from all multicast message receivers. Thus, the present invention proposes exploiting the additive properties of a wireless channel. The scheme of the present invention is thereby applicable to all kinds of networks and application scenarios, in which a reliable multicast communication plays an important role. An exemplary application scenario is vehicular-to-vehicular communication, as shown in Fig. 7. In

this application scenario, the vehicle denoted as Car A may be the transmitter of a multicast message, and may accordingly receive feedback messages from a plurality of other vehicles.

The present invention describes specifically three specific approaches (the approaches differing in the performance and the amount of information needed at the transmitter and receiver side, respectively) for the scheme of transmitting feedback acknowledgement messages simultaneously, and then reconstructing the desired information at the original multicast transmitter from a superposition of these messages.

A first aspect of the present invention provides a network device, preferably a base station, configured to receive a signal comprising a plurality of superimposed messages, wherein each message is sent by one of a plurality of terminal devices and has one of two possible logical values “true” and “false”, determine a logical conjunction or disjunction of the superimposed messages based on a comparison of the received signal with a threshold value.

The network device can efficiently determine from the determined conjunction or disjunction, whether the multicast message was decoded successfully by all terminal devices or not. In particular, if the logical conjunction or disjunction of the messages is “true”, then all messages have a value “true”, indicating that each terminal device decoded the multicast message successfully. In this case, the multicast message does not have to be sent again. If the conjunction or disjunction is “false”, then at least one message has a value “false”, which means preferably that the multicast message is sent again.

The network device, by comparing against the threshold value, can take a comparatively quick, but still reliable decision concerning the conjunction or disjunction. Since the logical conjunction or disjunction is determined, it would not matter if one or more terminal devices would not send any message with value “true, if they are able to decode the multicast message. Only messages with value “false” are required, when the decoding is unsuccessful. Thereby, resource waste can be reduced significantly.

In an implementation form of the first aspect, the network device is further configured to for determining the logical conjunction or disjunction of the superimposed messages, apply a hypothesis test, preferably a Neyman-Pearson test, based on the threshold value.

The hypothesis test allows taking a reliable decision concerning the conjunction or disjunction, i.e. at least controlling the most important error rate, while being fast and efficient.

In a further implementation form of the first aspect, the threshold value is based on a predetermined minimum power σ^2 of the received signal and a noise power σ_N^2 .

Based on such a threshold value, a reliable decision can be taken, and error probabilities can be well balanced.

In a further implementation form of the first aspect, if either channel coefficients between the network device and the terminal devices or the predetermined minimum power σ^2 are available at the network device, the threshold value is determined by a noise-free constellation point given that the logical conjunction or disjunction of the message is “true”, a closest noise-free constellation point given that the logical conjunction or disjunction of the message is “false”, and a noise distribution, wherein the threshold value is preferably in the range between the two constellation points.

Thus, the network device can make use of side information, in order to improve the reliability of the determination.

In a further implementation form of the first aspect, if a number of the plurality of terminal devices is available at the network device, the noise-free constellation point is $-\frac{\sigma}{\sqrt{2}}$, and/or the closest noise-free constellation point is $\frac{\sigma}{\sqrt{2}}$.

In a further implementation form of the first aspect, if a number of the plurality of terminal devices is not available at the network device, the noise-free constellation point is 0, and the closest noise-free constellation point is $\frac{\sigma}{\sqrt{2}}$.

The above two approaches provide reliable threshold values for the two cases that the side information of the number of terminal devices is available or not.

In a further implementation form of the first aspect, if a number of the plurality of terminal devices and channel coefficients between the network device and the terminal devices are not available at the network device, the threshold value is in a range between $\frac{1}{2} \sigma_N^2$ and $\frac{1}{2} (\sigma_N^2 + \sigma^2)$.

- 5 This approach works well, if no side information is available to improve the reliability of the determination.

In a further implementation form of the first aspect, each message is a single-bit message.

- 10 Accordingly, the amount of transmitted data can be reduced.

In a further implementation form of the first aspect, the network device is configured to distribute at least two sequences to each of the terminal devices, wherein each message is one of the sequences.

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The use of such sequences helps countering interference in the transmission of the messages from the terminal devices to the network device.

- 20 A second aspect of the present invention provides a terminal device, preferably a user equipment, configured to receive a multicast message from a network device, send at least one message having, of two possible logical values “true” and “false”, the logical value “false” to the network device, if the terminal device was not able to decode the multicast message, wherein the terminal device is configured to send the message in a predetermined resource block shared with one or more other terminal devices.

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Due to the use of the shared resource block, messages of different terminal devices are superimposed. For the network device determining the conjunction or disjunction of the superimposed messages, it is sufficient to send only a message with value “false”, in case that the decoding was unsuccessful. Thus, resource waste can be significantly reduced.

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In particular, in case of multiple terminal devices, all the terminal devices can transmit their message immediately and concurrently, for example, when the transmission of the original multicast message is finished. As shared resource block, there may, for instance, be defined a

fixed duration for the transmission of the messages. This fixed duration advantageously does not grow with the number of terminal devices receiving the multicast message.

5 In an implementation form of the second aspect, the terminal device is configured to, if a channel coefficient between the terminal device and the network device is available at the terminal device, encode the message having the logical value “false” according to a first determined encoding scheme, before sending it to the network device, and either encode a message having the logical value “true” according to a second determined encoding scheme, if the network device was able to decode the multicast message, and send it to the network device,
10 or not send any message to the network device, if the terminal device was able to decode the multicast message.

This encoding is selected advantageously, in case the side information is available, in order to improve the reliability. The sending of also the “true” message increases the amount of data,
15 but improves the reliability.

In a further implementation form of the second aspect, the terminal device is configured to, if a channel coefficient between the terminal device and the network device is not available at the terminal device, encode the message having the logical value “false” according to a random
20 encoding scheme, before sending it to the network device, and not send any message to the network device, if the terminal device was able to decode the multicast message.

This encoding is selected advantageously, in case the side information is not available, for best reliability.
25

In a further implementation form of the second aspect, each message is a single-bit message.

As mentioned above, this reduces the amount of transmitted data.

30 In a further implementation form of the second aspect, each message is one of at least two sequences, and the terminal device is configured to obtain the at least two sequences from the network device or the at least two sequences are preconfigured at the terminal device.

As mentioned above, this counters interference in the transmission between the terminal device and the network device.

A third aspect of the present invention provides a system of a network device according to the first aspect and its implementation forms, respectively, and a plurality of terminal devices according to the second aspect and its implementation forms, respectively, wherein the network device is configured to send the multicast message to the terminal devices, and each terminal device is configured to send the at least one message having the logical value “false” in the same predetermined resource block as the one or more other terminal devices.

The system of the third aspect achieves all advantages and effects of the network device of the first aspect, and the terminal device of the second aspect, respectively.

A fourth aspect of the present invention provides a method for a network device, comprising the steps of receiving a signal comprising a plurality of superimposed messages, wherein each message is sent by one of a plurality of terminal devices and has one of two possible logical values “true” and “false”, determining a logical conjunction or disjunction of the superimposed messages based on a comparison of the received signal with a threshold value.

In an implementation form of the fourth aspect, the method comprises, for determining the logical conjunction or disjunction of the superimposed messages, applying a hypothesis test, preferably a Neyman-Pearson test, based on the threshold value.

In a further implementation form of the fourth aspect, the threshold value bases on a predetermined minimum power σ^2 of the received signal and a noise power σ_N^2 .

In a further implementation form of the fourth aspect, if either channel coefficients between the network device and the terminal devices or the predetermined minimum power σ^2 are available at the network device, the threshold value is determined by a noise-free constellation point given that the logical conjunction or disjunction of the message is “true”, a closest noise-free constellation point given that the logical conjunction or disjunction of the message is “false”, and a noise distribution, wherein the threshold value is preferably in the range between the two constellation points.

In a further implementation form of the fourth aspect, if a number of the plurality of terminal devices is available at the network device, the noise-free constellation point is $-\frac{\sigma}{\sqrt{2}}$, and/or the closest noise-free constellation point is $\frac{\sigma}{\sqrt{2}}$.

- 5 In a further implementation form of the fourth aspect, if a number of the plurality of terminal devices is not available at the network device, the noise-free constellation point is 0, and the closest noise-free constellation point is $\frac{\sigma}{\sqrt{2}}$.

- 10 In a further implementation form of the fourth aspect, if a number of the plurality of terminal devices and channel coefficients between the network device and the terminal devices are not available at the network device, the threshold value is in a range between $\frac{1}{2}\sigma_N^2$ and $\frac{1}{2}(\sigma_N^2 + \sigma^2)$.

In a further implementation form of the fourth aspect, each message is a single-bit message.

- 15 In a further implementation form of the fourth aspect, the method comprises distributing at least two sequences to each of the terminal devices, wherein each message is one of the sequences.

The method of the fourth aspect and its implementation forms achieves all the advantages and effects of the network device of the first aspect and its implementation forms.

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A fifth aspect of the present invention provides a method for a terminal device, comprising the steps of, receiving a multicast message from a network device, sending at least a message having, of two possible logical values “true” and “false”, the logical value “false” to the network device, if the multicast message could not be decoded, wherein the message is sent in a
25 predetermined resource block shared with one or more other terminal devices.

- 30 In an implementation form of the fifth aspect, the method further comprise, if a channel coefficient between the terminal device and the network device is available at the terminal device, encoding the message having the logical value “false” according to a first determined encoding scheme, before sending it to the network device, and either encoding a message having the logical value “true” according to a second determined encoding scheme, if the network device was able to decode the multicast message, and sending it to the network device,

or not send any message to the network device, if the terminal device was able to decode the multicast message.

In a further implementation form of the fifth aspect, the method comprises, if a channel coefficient between the terminal device and the network device is not available at the terminal device, encoding the message having the logical value “false” according to a random encoding scheme, before sending it to the network device, and not sending any message to the network device, if the terminal device was able to decode the multicast message.

In a further implementation form of the fifth aspect, each message is a single-bit message.

In a further implementation form of the fifth aspect, each message is one of at least two sequences, and the method comprises obtaining the at least two sequences from the network device or preconfiguring the at least two sequences at the terminal device.

The method of the fifth aspect and its implementation forms achieves all the advantages and effects of the terminal device of the second aspect and its implementation forms.

It has to be noted that all devices, elements, units and means described in the present application could be implemented in the software or hardware elements or any kind of combination thereof. All steps which are performed by the various entities described in the present application as well as the functionalities described to be performed by the various entities are intended to mean that the respective entity is adapted to or configured to perform the respective steps and functionalities. Even if, in the following description of specific embodiments, a specific functionality or step to be performed by external entities is not reflected in the description of a specific detailed element of that entity which performs that specific step or functionality, it should be clear for a skilled person that these methods and functionalities can be implemented in respective software or hardware elements, or any kind of combination thereof.

BRIEF DESCRIPTION OF DRAWINGS

The above described aspects and implementation forms of the present invention will be explained in the following description of specific embodiments in relation to the enclosed drawings, in which

- Fig. 1 shows a network device according to an embodiment of the present invention.
- Fig. 2 shows a terminal device according to an embodiment of the present invention.
- 5 Fig. 3 shows a method according to an embodiment of the present invention.
- Fig. 4 shows a method according to an embodiment of the present invention.
- 10 Fig. 5 shows a message flow between a network device and three terminal devices according to embodiments of the present invention.
- Fig. 6 shows a conventional feedback acknowledgement transmission scheme.
- 15 Fig. 7 shows an application scenario of a feedback acknowledgement transmission scheme.

DETAILED DESCRIPTION OF EMBODIMENTS

- 20 Fig. 1 highlights a network device 100 according to an embodiment of the present invention. The network device 100 is preferably a BS, and is associated and/or communicating with one or more terminal devices 200, which are preferably UEs.

In particular, the network device 100 is configured to receive a signal, which comprises a
25 plurality of superimposed messages 101. Each of these messages 101 is sent by one of the terminal devices 200, and has one of two possible logical values “true” and “false”. These possible logical values could alternatively be referred to as “1” and “0”, or vice versa, or “ACK” and “NACK”, or by any other binary coding.

- 30 The network device 100 is then configured to determine a logical conjunction or disjunction of the superimposed messages 101 based on a comparison of the received signal with a threshold value. That is, the network device 100 can determine, whether the logical conjunction or disjunction of the messages 101 is “true” or “false” (as indicated in Fig. 1), or is equivalently “1” or “0” or the like. The logical conjunction of the superimposed messages 101 is particularly

“true”, if each message 101 is “true”. The logical conjunction of the superimposed messages 101 is furthermore “false”, if at least one of the messages 101 is “false”. The logical disjunction of the superimposed messages 101 is particularly “true”, if at least one of the messages 101 is “true”. The logical disjunction of the superimposed messages 101 is furthermore “false” if each
5 message 101 is “false”. In the following, the description is continued only with reference to the “logical conjunction”. However, the principles of the invention can be applied likewise for the “logical disjunction”, or for any other equivalent logical function.

Fig. 2 highlights accordingly one of the terminal devices 200, which is associated with and/or
10 communicating with the network device 100. This terminal device 200 according to an embodiment of the present invention is preferably a UE.

The terminal device 200 is configured to receive a multicast message 201 from the network device 100. In response, the terminal device 200 sends at least one message 101 having, of two
15 possible logical values “true” and “false”, the logical value “false” to the network device 100, if the terminal device 200 was not able to decode the multicast message 201. Again, the logical values can also be referred to as “1” and “0” or vice versa, or “ACK” and “NACK”, or by any other binary coding. That is, the terminal device 100 feeds back a message 101 to the terminal device 100 at least when it fails to decode the multicast message 201. In this case, the multicast
20 message 201 should be sent again by the network device 100.

The terminal device 200 may further be configured to send also a message 101 having the logical value “true” to the network device 100, if the terminal device 200 was able to decode the multicast message 201, in order to improve the reliability of the determination at the network
25 device 100. Alternatively, the terminal device 200 may be configured to not send any message 101 to the network device 100, if the terminal device 200 was able to decode the multicast message, in order to reduce significantly the amount of sent data.

In either case, the terminal device 200 is configured to send the at least one message 101 in a
30 predetermined resource block, which is shared with one or more other terminal devices 200. That is, all terminal devices 200 send their messages 101 in the same resource block, for instance, in the same time and/or frequency block. Accordingly, the messages 101 will be superimposed, as described above. If only one of these superimposed messages 101 has a logical value of “false”, then also the logical conjunction of the superimposed messages 101

will be “false”. In this case, the network device 100 may retransmit the multicast message 201. If all superimposed messages 101 have a logical value of “true”, then also the conjunction of the superimposed messages 101 is true. In this case, the multicast message 201 was distributed successfully to all terminal devices 200. Also, if the network device 100 receives no message 101 at all – in case that the terminal devices 200 feedback a message 101 only in case of a decode failure of the multicast message 201 – the multicast message 201 can be deemed successfully distributed.

Fig. 3 shows a method 300 according to an embodiment of the present invention. The method 300 is for a network device 100, is preferably carried out by the network device 100 shown in Fig. 1, and comprises the following steps. A step 301 of receiving a signal comprising a plurality of superimposed messages 101, wherein each message 101 is sent by one of a plurality of terminal devices 200 and has one of two possible logical values “true” and “false”. And a step 302 of determining a logical conjunction of the superimposed messages 101 based on a comparison of the received signal with a threshold value.

Fig. 4 shows another method 400 according to an embodiment of the present invention. The method 400 is for a terminal device 200, is preferably carried out by the terminal device 200 shown in Fig. 2, and comprises the following steps. A step 401 of receiving 401 a multicast message 201 from a network device 100. And a step 402 of sending at least a message 101 having, of two possible logical values “true” and “false”, the logical value “false” to the network device 100, if the multicast message 201 could not be decoded. In particular, the message 101 is thereby sent in a predetermined resource block shared with one or more other terminal devices 200.

According to the proposed feedback transmission scheme, after transmitting the multicast message 201 is finished, all the terminal devices 200 feedback their “true/false” messages 101 (in the following referred to as “ACK/NACK”, as in e.g. LTE) simultaneously on the same shared wireless resource. Each message 101 may thereby be a single-bit message, in order to keep the amount of exchanged data at a minimum. Alternatively, some sequences (either pre-assigned by the network device 100 or pre-configured at the terminal devices 200) can be exploited instead of the single bits, in order to help counter interference and malicious attempts in the transmission of the ACK/NACK. In particular, each message 101 may be one of at least two sequences.

Thereafter, the network device 100 determines from the superimposed messages 101 a joint acknowledgement, i.e. the conjunction of the messages 101, by exploiting the additive properties of the wireless channel. Advantageously, the network device 101 does not need to reconstruct all the individual sent messages 101, but only the logical conjunction, in order to decide if the multicast message needs 201 to be retransmitted or not. This makes the scheme particularly efficient. Details for the proposed scheme, i.e. how to determine by the network device 100 the logical conjunction of the ACK/NACK from the received superposition of the messages 101, will be explained further below. In particular, appropriately choosing decision thresholds for determining “false” or “true” concerning the conjunction will be highlighted.

An example of a message flow between a network device 100 according to an embodiment of the present invention, and three terminal devices 200 according to embodiments of the present invention, is shown in Fig. 5. Fig. 5 specifically shows a typical multicast transmission from a BS as the network device 100 to multiple UEs (UE1, UE2, UE3) as the terminal devices 200. The BS 100 may optionally distribute specific sequences to the UEs 200. The BS 100 sends a multicast message 201 to the UEs 200, and the UEs 200 respond with messages 101 according to ACK or NACK. Then, the BS 200 checks 302 a threshold for determining the logical conjunction of the superimposed messages 101, as described previously. In case that the logical conjunction is NACK (“false”), the BS 100 may retransmit the multicast message 201. Notably, in case of a side-link multicast transmission, the multicast message 201 and the ACK/NACK messages 101 are sent and received by one of the UEs accordingly.

In the present invention, specifically three approaches are presented for decoding the logical conjunction of the ACK/NACK from the received superposition of messages 101, the approaches depending on how much side information is available at the terminal devices 200 and the network device 100, respectively.

A first approach targets to decode the logical conjunction of the superimposed messages 101, in case that at the network device 100, either channel coefficients between the network device 100 and the terminal devices 200, or a predetermined minimum power σ^2 of the signal received by the network device 100 from the terminal devices 200, are available. And, if also at the network device 100, a number of the plurality of terminal devices 200 is available. And, if also

at the terminal device 200, the channel coefficient between the terminal device 200 and the network device 100 is available.

A second approach eases some requirements of the first approach. This approach applies, if either the channel coefficients between the network device 100 and the terminal devices 200, or the predetermined minimum power σ^2 , are available at the network device 200. And accordingly, if also at the terminal device 200, the channel coefficient between the terminal device 200 and the network device 100 is available. However, contrary to the first approach, it is not necessary that the number of terminal devices 100 is available at the network device 100 side.

A third approach targets to decode the logical conjunction without any of this side information. That is, a channel coefficient between the terminal device 200 and the network device 100 is neither available at the terminal device 200 nor the network device.

In all three approaches, tools from statistics are used, in order to exercise additional control over error probabilities. The goal is to decode the logical conjunction of the messages 101. If the network device 100 decides on a result of “true”, although at least one of the transmitted messages 101 was “false”, this is called a type 1 error. If the network device 100 on the other hand decides on an outcome of “false”, although all the transmitted messages 101 were all “true”, this is called that a type 2 error. Typically, a relatively large fraction of one type of error can be tolerated, while the other type needs to be more strictly controlled. In the present case of the feedback to the multicast message 201, a type 1 error would mean that the multicast message 201 is not repeated by the network device 100, although at least one of the terminal devices 200 could not correctly decode it. A type 2 error would mean that the multicast message 201 is unnecessarily repeated, since all terminal devices 200 could correctly decode it already the first time. Thus, the type 1 error causes unreliability in the multicast communication, whereas the type 2 error causes a waste of wireless resources (which is, however, moderate, if the error probability is not excessively large).

Therefore, it may be preferable to keep the type 1 error at a fixed (but very low) value, while making use of the available wireless resources to make the type 2 error as small as possible (given the fixed value of the type 1 error). This can be accounted for by using a statistical hypothesis test at the network device 100 side. Accordingly, for determining the logical

conjunction of the superimposed messages 101, the network device 100 is preferably configured to apply a hypothesis test, more preferably a Neyman-Pearson test, based on the threshold value. The threshold values for the three different approaches explained above differ, and are described further below. For each approach, however, the threshold value preferably
 5 bases on a predetermined minimum power σ^2 of the received signal and a noise power σ_N^2 .

Notably, it would be easily possible for the skilled person to switch the roles of the two types of error with an only slightly modified construction.

10 In all three approaches, a network comprising n terminal devices 200, which are denoted as $T_1, \dots, T_n$, and a network device 100, which is denoted as R , are considered. Each terminal device 200 T_j may transmit a message 101 with, for instance, a single bit of information $t_j \in \{0,1\}$ indicating its feedback message 101 (“false”, “true”) to the multicast message 201. The network device 100 aims to reconstruct $t := t_1 \wedge \dots \wedge t_n \in \{0,1\}$ such that t is the logical
 15 conjunction of all the t_j (where 0 corresponds to the logical value of “false” and 1 to the logical value of “true”).

The messages 101 transmitted simultaneously by the terminal devices 200 get superimposed in the wireless channel. The channel coefficient between each terminal device 200 and the network
 20 device 100 is denoted by $h_1, \dots, h_n \in \mathbb{C}$. Therefore, if each terminal device 200 T_j sends the signal X_{jk} at time instant k , the signal Y_k obtained at the network device 100 is

$$Y_k = \sum_{j=1}^n h_j X_{jk} + N_k,$$

25 where $(N_1, \dots, N_\ell)$ is white noise in the wireless channel, which can be modelled by a sequence of identically and independently distributed (i.i.d) complex Gaussian random variables with 0 mean and standard deviation $\frac{\sigma_N}{\sqrt{2}}$ (in each of the complex components). By the Nyquist sampling theorem, there is a direct correspondence between the number of channel uses ℓ and the transmission duration and bandwidth of a signal in a continuous channel.

30

Thus, it is further denoted

$$\sigma := \min_{j \in \{1, \dots, n\}} |h_j| \sigma_j$$

where σ_j is the signal variance by the terminal device T_j and the signal-to-noise ratio is defined as

5

$$SNR := \frac{\sigma^2}{\sigma_N^2}.$$

σ^2 is the predetermined minimum power of the signal comprising the superimposed messages 101, which is received by the network device 100. σ_N^2 denotes the noise power.

10

An encoder at a terminal device 200 is configured to map each of the transmit messages t_j to a signal vector $(X_{j1}, \dots, X_{jk})$. For the first and second approach explained above, the encoding process can be described as

15

$$E_j: \{0,1\} \rightarrow \mathbb{C}^k,$$

where also a power constraint may be imposed according to

$$|e_\ell|^2 \leq \sigma_j^2$$

20

for each component e_ℓ of the encoder output $(e_1, \dots, e_k)$.

The encoding process for the third approach explained above, however, will be stochastic and instead the following expectation is limited

25

$$\mathbb{E}(|X_{jk}|^2) \leq \sigma_j^2.$$

A decoder at the network device 100 is a function

30

$$D: \mathbb{C}^\ell \rightarrow \{0,1\}$$

configured to map the received signal vector $(Y_1, \dots, Y_\ell)$ to an estimated signal $\hat{t}$.

The type 1 error probability introduced above (i.e. the probability that $\hat{t} = 1$ given that $t := t_1 \wedge \dots \wedge t_n = 0$) is denoted by α , and the type 2 error probability introduced above (i.e. the probability that $\hat{t} = 0$ given that $t = t_1 \wedge \dots \wedge t_n = 1$) is denoted by β . The preferred target of the scheme of the present invention implemented by network device 100 and terminal devices 200 is to keep both α and β as small as possible, by using a properly designed decoding algorithm.

Now, the first approach is described in more detail. The first approach targets to decode the logical conjunction $t := t_1 \wedge \dots \wedge t_n$ of the feedback messages 101 that are transmitted simultaneously from the terminal devices 200 to the network device 100, in case that at the network device 100 side, either channel coefficients between the network device 100 and the terminal devices 200, or a predetermined minimum power σ^2 of the signal received by the network device 100 from the terminal devices 200, are available. And, if also at the network device 100, a number of the plurality of terminal devices 200 is available. The number of terminal devices 200 can be obtained by the network device 100, since – being the original multicast message 201 transmitter – it is aware of the multicast destinations. Also the other assumption is reasonable, in particular if a reciprocal wireless channel is used, and its coherence time is long compared to the duration of the acknowledgement messages 101, because the original multicast message 201 could for instance contain pilot symbols, from which the transmitters can perform channel estimation to measure the channel state and channel coefficients. Alternatively, the channel coefficients can also be obtained by the terminal devices 200 via statistical channel knowledge or long-term observation. The first approach can be suitably applied to TDD systems with deterministic receivers.

In this approach, each terminal device T_j knows its own channel coefficient h_j and the network device 100 knows the number of the terminal devices 200, which can be given by the sum

$$\sum_{j=1}^n |h_j| \sigma_j.$$

Generally speaking, in this first approach the terminal device 200 is configured to encode a message 101 having the logical value “false” according to a first determined encoding scheme, before sending it to the network device 100, and encode a message 101 having the logical value “true” according to a second determined encoding scheme, and send it to the network device 100.

Specifically, the encoding function E_j at the terminal device T_j may preferably be defined in the first approach as

$$E_j(t_j) := \begin{cases} \frac{\sigma_j + i\sigma_j}{\sqrt{2}} \exp(-i \arg(h_j)), & t_j = 0 \\ -\frac{\sigma_j + i\sigma_j}{\sqrt{2}} \exp(-i \arg(h_j)), & t_j = 1. \end{cases}$$

That is, if the original multicast message 201 is successfully decoded ($t_j = 1$) at the terminal device 200, the feedback message 101 is encoded as $-\frac{\sigma_j + i\sigma_j}{\sqrt{2}} \exp(-i \arg(h_j))$ and transmitted as an ACK (“true”), while the NACK (“false”) is encoded and transmitted as $\frac{\sigma_j + i\sigma_j}{\sqrt{2}} \exp(-i \arg(h_j))$, if the decoding of the original multicast message 201 ends in a failure ($t_j = 0$).

All the terminal devices 200 send their individual encoded messages 101 to the network device 100 simultaneously on the same wireless resource, and the transmitted signals get superimposed in the wireless channel. Then the component Y_k of the received vector Y obtained by the receiver at time instant k is

$$\begin{aligned} Y_k &= \sum_{t_j=0} h_j \frac{\sigma_j + i\sigma_j}{\sqrt{2}} \exp(-i \arg(h_j)) - \sum_{t_j=1} h_j \frac{\sigma_j + i\sigma_j}{\sqrt{2}} \exp(-i \arg(h_j)) + N_k \\ &= \sum_{t_j=0} |h_j| \frac{\sigma_j + i\sigma_j}{\sqrt{2}} - \sum_{t_j=1} |h_j| \frac{\sigma_j + i\sigma_j}{\sqrt{2}} + N_k \end{aligned}$$

which consists of a positive factor resulting from the NACKs (“false” messages 101), a negative factor resulting from the ACKs (“true” messages 101), and an additional noise factor.

Since the channel coefficients and the number of transmitters $\sum_{j=1}^n |h_j| \sigma_j$ are known by the network device 100, it is then configured to compute $Y' = (Y'_1, \dots, Y'_\ell)$ over all channel uses by cancelling out the negative factor brought by the ACKs, which is given by

$$Y'_k := Y_k + \frac{1}{\sqrt{2}} \sum_{j=1}^n |h_j| \sigma_j (1 + i) = 2 \sum_{t_j=0} |h_j| \frac{\sigma_j + i \sigma_j}{\sqrt{2}} + N_k.$$

If now the real and imaginary parts of Y' are considered separately, a sequence $(\hat{Y}_1, \dots, \hat{Y}_{2\ell})$ of 2ℓ identically and independently distributed random samples is obtained. They follow a Gaussian distribution, which has mean

$$\sqrt{2} \sum_{t_j=0} |h_j| \sigma_j.$$

Therefore, the mean is 0, if $t = 1$ and at least $\sqrt{2}\sigma$, if $t = 0$. Now preferably a Neyman-Pearson test can be constructed for the null hypothesis that the mean is (at least) $\sqrt{2}\sigma$ and the alternative hypothesis that the mean is (at most) 0.

Generally speaking, in this first approach the threshold value is determined by a noise-free constellation point given that the logical conjunction of the message is “true”, a closest noise-free constellation point given that the logical conjunction of the message is “false”, and a noise distribution. Thereby, the noise-free constellation point given that the logical conjunction of the message is “true” is $-\frac{\sigma}{\sqrt{2}}$, and the closest noise-free constellation point given that the logical conjunction of the message is “false” is $\frac{\sigma}{\sqrt{2}}$.

Specifically, the decoder of the network device 100 is preferably configured in the first approach to function as

$$D(\hat{Y}_1, \dots, \hat{Y}_{2\ell}) := \begin{cases} 0, & \sum_{k=1}^{2\ell} \hat{Y}_k > c \\ 1, & \sum_{k=1}^{2\ell} \hat{Y}_k \leq c \end{cases}$$

with

$$c := \Phi^{-1}(\alpha)\sqrt{\ell}\sigma_N + 2\sqrt{2}\ell\sigma,$$

5

where c is the decision threshold and Φ^{-1} denotes the quantile function of the standard Gaussian distribution.

Regarding the robustness of this first approach, it is worth noting that the exact value of the noise power is not required for the construction of the encoders and decoder, but rather it suffices to construct the test with some $\sigma'_N \geq \sigma_N$. Then, if the actual noise has lower power than the one used in the construction, the error probabilities will be lower (at least not higher) than in the calculation. This is true unless the decision threshold is higher than the null hypothesis mean of $2\sqrt{2}\ell\sigma$ (which can occur, however, only if the type 1 error is more than one half).

15

A slight modification can be made to further relax the requirements of the first approach, where the network device 100 only needs to know n and all terminal devices 200 need to know σ , which is defined above or alternatively even arbitrary, if all the terminal devices 200 and the network device 100 agree on a common received signal strength such that $\sigma \leq |h_j|\sigma_j$ (not necessarily with equality) for all j .

20

In this case, all terminal devices 200 can use a common encoder according to

$$E(t_j) := \begin{cases} \frac{\sigma + i\sigma}{\sqrt{2}h_j}, & t_j = 0 \\ -\frac{\sigma + i\sigma}{\sqrt{2}h_j}, & t_j = 1. \end{cases}$$

25

And the terminal devices 200 also attenuate their signal transmission power accordingly as

$$\frac{\sigma^2}{|h_j|^2} \leq \frac{|h_j|^2 \sigma_j^2}{|h_j|^2} = \sigma_j^2$$

and thus does not violate the power constraint. This way, the expression that the decoder at the network device 100 uses to compute Y'_k from Y_k becomes

$$Y'_k := Y_k + \frac{1}{\sqrt{2}} n \sigma (1 + i)$$

5

and so the decoder only needs to know n and σ and not the actual sum of maximum received signal powers, which not only depends on the transmitter power constraints, but also on the channel state.

- 10 Now, the second approach is described in more detail. This approach is a modification of the first approach, in which the network device 100 does not need to know the number of terminal devices 200. It is still required, however, that the terminal devices 200 have knowledge of their channel coefficients to the network device 100, and that the channel coefficients between the network device 100 and the terminal devices 200, or the predetermined minimum power σ^2 , are
15 available at the network device 100.

This approach is suitable for TDD systems without deterministic receivers at the network device 100, e.g., in broadcast like communications.

- 20 Generally speaking, in the second approach the terminal device 200 is configured to encode the message 101 having the logical value “false” according to a first determined encoding scheme, before sending it to the network device 100, and not send any message 101 to the network device 100, if the terminal device 200 was able to decode the multicast message 201.

- 25 Specifically, the encoders at the terminal devices 200 can preferably be defined to be

$$E_j(t_j) := \begin{cases} \frac{\sigma_j + i\sigma_j}{\sqrt{2}} \exp(-i \arg(h_j)), & t_j = 0 \\ 0, & t_j = 1. \end{cases}$$

This results in a received signal

30

$$Y_k = \sum_{t_j=0} |h_j| \frac{\sigma_j + i\sigma_j}{\sqrt{2}} + N_k.$$

Again the real and imaginary parts are considered separately to obtain a sequence $(\hat{Y}_1, \dots, \hat{Y}_{2\ell})$ of independently and identically distributed samples (e.g., of a Gaussian distribution). The variance is that of the noise $\frac{\sigma_N}{\sqrt{2}}$ and the mean is

5

$$\frac{1}{\sqrt{2}} \sum_{t_j=0} |h_j| \sigma_j.$$

Therefore, the mean is 0 if $t = 1$ and it is (at least) $\frac{\sigma}{\sqrt{2}}$ if $t = 0$.

10 Again, preferably a Neyman-Pearson test is constructed for the null hypothesis that the mean is (at least) $\frac{\sigma}{\sqrt{2}}$ and the alternative hypothesis that the mean is 0.

Generally speaking, in the second approach the threshold value is determined by a noise-free constellation point given that the logical conjunction of the message is “true”, a closest noise-free constellation point given that the logical conjunction of the message is “false”, and a noise distribution, wherein the noise-free constellation point given that the logical conjunction of the message is “true” is 0 and the closest noise-free constellation point given that the logical conjunction of the message is “false” is $\frac{\sigma}{\sqrt{2}}$.

20 Specifically, the decoder at the network device 100 may preferably take the form

$$D(\hat{Y}_1, \dots, \hat{Y}_{2\ell}) := \begin{cases} 0, & \sum_{k=1}^{2\ell} \hat{Y}_k > c \\ 1, & \sum_{k=1}^{2\ell} \hat{Y}_k \leq c \end{cases}$$

where the decision threshold is

25

$$c := \Phi^{-1}(\alpha) \sqrt{\ell} \sigma_N + \sqrt{2\ell} \sigma.$$

Regarding the robustness of the second approach, it is worth noting that similarly to the remark for the first approach, the test can be constructed at the decoder with values $\sigma'_N \geq \sigma_N$ and $\sigma' \leq$

σ . The theoretical error bounds will be worse than they would be if the actual values were used, but they will be achieved as long as the actual values are within the given ranges (and the type one error is not chosen to be larger than one half).

5 Now, the third approach is described in more detail. For this approach, channel coefficients between the terminal devices 200 and the network device 100 need not be available at the terminal devices 200 and the network device, respectively. Nor is the number of terminal devices 200 required to be available at the network device 100. This kind of assumption suits perfectly for communications in FDD systems.

10

In order to decode the logical conjunction $t := t_1 \wedge \dots \wedge t_n$ of the feedback messages 101 from the terminal devices 200 without the side information on the channels coefficients and the number of terminal devices 200, a probability distribution for the transmitted signal is used, which is invariant to the phase shift component of the channel coefficients.

15

Generally speaking, in the third approach the terminal device 200 is configured to encode the message 101 having the logical value “false” according to a random encoding scheme, before sending it to the network device 100, and not send any message 101 to the network device 100, if the terminal device 200 was able to decode the multicast message 201.

20

Specifically, the encoder E_j of the terminal device 200 may preferably output 0, if $t_j = 1$, and a complex Gaussian distributed value with mean 0 and a variance of $\frac{\sigma_j^2}{2}$ in each complex component, if $t_j = 0$, which can be presented as

25
$$E_j(t_j) := \begin{cases} X_j \sim N(0, \frac{\sigma_j^2}{2}), & t_j = 0 \\ 0, & t_j = 1. \end{cases}$$

The received signal at time instant k is

$$Y_k = \sum_{t_j=0} h_j X_{jk} + N_k = \sum_{t_j=0} |h_j| X'_{jk} + N_k$$

30

where (X'_{jk}) have the same distribution as (X_{jk}) which is i.i.d Gaussian with mean 0 and variance $\frac{\sigma_J^2}{2}$ in each complex component.

By considering real and imaginary parts separately, a sequence $(\hat{Y}_1, \dots, \hat{Y}_{2\ell})$ is obtained of i.i.d

- 5 Gaussian samples with mean 0 and a variance of $\frac{\sigma_N^2}{2}$ if $t = 1$ and (at least) $\frac{\sigma^2}{2} + \frac{\sigma_N^2}{2}$ if $t = 0$.

Generally speaking, in the third approach the threshold value is in a range between $\frac{1}{2}\sigma_N^2$ and $\frac{1}{2}(\sigma_N^2 + \sigma^2)$.

- 10 Specifically, the decoder at the network device 100 may preferably take the form

$$D(\hat{Y}_1, \dots, \hat{Y}_{2\ell}) := \begin{cases} 0, & \sum_{k=1}^{2\ell} \hat{Y}_k^2 > c \\ 1, & \sum_{k=1}^{2\ell} \hat{Y}_k^2 \leq c \end{cases}$$

wherein the decision threshold c is

15
$$c := F_{\chi_{2\ell}^2}^{-1}(\alpha) \frac{\sigma^2 + \sigma_N^2}{2},$$

where $F_{\chi_{2\ell}^2}^{-1}$ denotes the quantile function of the Chi-Squared distribution with 2ℓ degrees of freedom.

- 20 This third approach is robust against the use of a too low value for σ , but contrary to first and second approaches, the approach is sensitive to using a wrong value for the noise power.

In all three approaches, some sequences can be exploited to help counter interference in the transmission of the ACK/NACK from the terminal devices 200 to the network device 100. The first and second approach can specifically be extended to make use of spreading sequences. The sequences used for ACK/NACK feedback may be transmitted in advance to terminal devices

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200 in the network by the network device 100. Alternatively, the sequences can be preconfigured at the terminal devices 200.

A problem that has to be considered while doing this is that robustness against time shifts of the transmitted signals should be retained. It is assumed that the received signal of each terminal device j arrives shifted in time by ℓ_j channel uses, where ℓ_j is unknown, but guaranteed to be in the set $\{-L, \dots, L\}$ for a given $L \geq 0$. It is further assumed that communication is obstructed by an interference process $(I_k)_{k \in I}$ and Gaussian noise N_k as before.

It is also assumed the existence of a complex-valued sequence $(s_k)_{k \in \{1, \dots, \ell\}}$ with entries of absolute value 1 such that the autocorrelation of s with cyclic shifts of itself is ℓ if the shift is by a multiple of ℓ elements and 0 if the shift is by more than 0 but at most L elements (in either direction). Moreover, it is assumed that the correlation of cyclic shifts of s with subsequences of I is close to 0. These assumptions are met (or closely met) for many widely-used spreading sequences, for instance when s is chosen to be a Zadoff-Chu sequence of length ℓ and I comes from communication which is spread with Zadoff-Chu sequences orthogonal to s .

First, an illustration on the spreading analogue for the first approach is provided. The encoder at the terminal device 200 to encode the message 101 to a sequence may be defined as

$$E_j(t_j) := \begin{cases} \frac{\tilde{s}}{h_j}, & t_j = 0 \\ -\frac{\tilde{s}}{h_j}, & t_j = 1, \end{cases}$$

where $\tilde{s}$ is the sequence s followed by its first $2L$ elements. Thus, the encoder at the terminal device 200 now needs $\ell + 2L$ channel uses instead of ℓ , however, this cost is small if L is much smaller than ℓ .

The components of the received vector Y_k are now

$$Y_k = \sum_{t_j=0} \tilde{s}(k + \ell_j) - \sum_{t_j=1} \tilde{s}(k + \ell_j) + N_k + I_k.$$

At the decoder of the network device 100, this is correlated with the sequence s in all possible cyclic shifts, and correlations are summed to get

$$\begin{aligned}
 5 \quad Y &= \sum_{k=L+1}^{\ell+L} \sum_{\tilde{l}=-L}^L \tilde{s}(k - \tilde{l}) Y_k \\
 &= \sum_{k=L+1}^{\ell+L} \sum_{\tilde{l}=-L}^L \tilde{s}(k - \tilde{l}) \left(\sum_{t_j=0} \tilde{s}(k + \ell_j) - \sum_{t_j=1} \tilde{s}(k + \ell_j) + N_k + I_k \right) \\
 &= \ell \left(\sum_{t_j=0} 1 - \sum_{t_j=1} 1 \right) + \sum_{k=L+1}^{\ell+L} N_k \sum_{\tilde{l}=-L}^L \tilde{s}(k - \tilde{l})
 \end{aligned}$$

10 The decoding can now continue as described above. Note, however, that compared to before the noise is now amplified by an additional factor of up to $(2L + 1)$, so this use of spreading sequences is only practical for very small L .

15 Similarly, in order to adapt the second approach for spreading, the encoder of the terminal device 200 should be adjusted to map the ACK message 101 with value “true” (or “1”) to the all-zero sequence, that is

$$E_j(t_j) := \begin{cases} \frac{\tilde{s}}{h_j}, & t_j = 0 \\ 0, & t_j = 1. \end{cases}$$

20 Then the components of the received vector Y_k and the corresponding sum of correlations Y are given as

$$\begin{aligned}
 Y_k &= \sum_{t_j=0} \tilde{s}(k + \ell_j) + N_k + I_k, \\
 Y &= \ell \left(\sum_{t_j=0} 1 \right) + \sum_{k=L+1}^{\ell+L} N_k \sum_{\tilde{l}=-L}^L \tilde{s}(k - \tilde{l}).
 \end{aligned}$$

25

For the third approach, the encoder of the terminal device 200 may map the ACK message 101 with value “true” to the all-zero sequence, and the message 101 with value “false” to a specified sequence for a given Gaussian distributed value. The decoding principle and the decision threshold are the same as described above.

5

All three proposed approaches can with little effort be modified in such a way that the roles of the type 1 and type 2 error are switched, i.e. that the error, which has been specified as type 2 above is the one, which can be strictly controlled, while the error specified above as type 1 is made as small as possible given the available resources.

10

For the first and second approach any signal of type

$$\frac{a_l \sigma_j + b_l i \sigma_j}{\sqrt{2}} \exp(-i \arg(h_j))$$

15

(and specifically for the first approach: also its additive inverse depending on the message 101 that is to be conveyed) can be sent at channel use l (of course, to fulfill the power constraint, we need $\frac{a_l^2 + b_l^2}{2} = 1$) so that the use of suitable spreading sequences would be possible to separate different multicast clusters. For reception, a matched filter would be necessary at the network device 100. But the summation of the received signals described for the first and

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second approach is also in effect a filter matched to the (particularly simple) signal given above.

For the third approach, in principle any circularly symmetric probability distribution could be used (like for instance a uniform distribution on a sphere or ball around zero). In any case, detection of the signal will amount to a measurement of received signal strength, but in the non-

25

Gaussian case, the establishment of analytical error bounds would be more complicated.

Regarding to the performance of the scheme of the present invention, the scheme of the present invention enables a more efficient, faster and more reliable feedback acknowledgement transmission for wireless multicast communication than a conventional scheme, e.g. the TDMA

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scheme. Thereby, the first approach (method 1) has the best performance (in terms of error probability versus transmitting power and transmission duration), while the third approach

(method 3) performs worst (but with only slightly performance degradation compared with the first and second approach, respectively), due to the lack of side information.

5 The present invention has been described in conjunction with various embodiments as examples as well as implementations. However, other variations can be understood and effected by those persons skilled in the art and practicing the claimed invention, from the studies of the drawings, this disclosure and the independent claims. In the claims as well as in the description the word “comprising” does not exclude other elements or steps and the indefinite article “a” or “an” does not exclude a plurality. A single element or other unit may fulfill the functions of several
10 entities or items recited in the claims. The mere fact that certain measures are recited in the mutual different dependent claims does not indicate that a combination of these measures cannot be used in an advantageous implementation.

CLAIMS

1. Network device (100), preferably a base station, configured to
 receive a signal comprising a plurality of superimposed messages (101), wherein each
 5 message (101) is sent by one of a plurality of terminal devices (200) and has one of two possible
 logical values “true” and “false”,
 determine a logical conjunction or disjunction of the superimposed messages (101)
 based on a comparison of the received signal with a threshold value.
- 10 2. Network device (100) according to claim 1, configured to
 for determining the logical conjunction or disjunction of the superimposed messages
 (101),
 apply a hypothesis test, preferably a Neyman-Pearson test, based on the threshold value.
- 15 3. Network device (100) according to claim 1 or 2, wherein
 the threshold value bases on a predetermined minimum power σ^2 of the received signal
 and a noise power σ_N^2 .
4. Network device (100) according to one of the claims 1 to 3, wherein
 20 if either channel coefficients between the network device (100) and the terminal devices
 (200) or the predetermined minimum power σ^2 are available at the network device (100),
 the threshold value is determined by a noise-free constellation point given that the
 logical conjunction or disjunction of the message is “true”, a closest noise-free constellation
 point given that the logical conjunction or disjunction of the message is “false”, and a noise
 25 distribution,
 wherein the threshold value is preferably in the range between the two constellation
 points.
5. Network device (100) according to claim 4, wherein
 30 if a number of the plurality of terminal devices (200) is available at the network device
 (100),
 the noise-free constellation point is $-\frac{\sigma}{\sqrt{2}}$, and/or
 the closest noise-free constellation point is $\frac{\sigma}{\sqrt{2}}$.

6. Network device (100) according to claim 4, wherein
if a number of the plurality of terminal devices (200) is not available at the network
device (100),

5 the noise-free constellation point is 0, and
the closest noise-free constellation point is $\frac{\sigma}{\sqrt{2}}$.

7. Network device (100) according to claim 3, wherein
if a number of the plurality of terminal devices (200) and channel coefficients between
10 the network device (100) and the terminal devices (200) are not available at the network device
(100),

the threshold value is in a range between $\frac{1}{2}\sigma_N^2$ and $\frac{1}{2}(\sigma_N^2 + \sigma^2)$.

8. Network device (100) according to one of the claim 1 to 7, wherein
15 each message (101) is a single-bit message.

9. Network device (100) according to one of the claims 1 to 7, configured to
distribute at least two sequences to each of the terminal devices (200), wherein
each message (101) is one of the sequences.

20 10. Terminal device (200), preferably a user equipment, configured to
receive a multicast message (201) from a network device (100),
send at least one message (101) having, of two possible logical values “true” and “false”,
the logical value “false” to the network device (100), if the terminal device (200) was not able
25 to decode the multicast message (201), wherein

the terminal device (200) is configured to send the message (101) in a predetermined
resource block shared with one or more other terminal devices (200).

11. Terminal device (200) according to claim 10, configured to
30 if a channel coefficient between the terminal device (200) and the network device (100)
is available at the terminal device (200),

encode the message (101) having the logical value “false” according to a first
determined encoding scheme, before sending it to the network device (100), and

either encode a message (101) having the logical value “true” according to a second determined encoding scheme, if the terminal device (200) was able to decode the multicast message (201), and send it to the network device (100),

5 or not send any message to the network device, if the terminal device was able to decode the multicast message.

12. Terminal device (200) according to claim 10, configured to
if a channel coefficient between the terminal device (200) and the network device (100) is not available at the terminal device (200),

10 encode the message (101) having the logical value “false” according to a random encoding scheme, before sending it to the network device (100), and

not send any message (101) to the network device (100), if the terminal device (200) was able to decode the multicast message (201).

15 13. Terminal device (200) according to one of the claims 10 to 12, wherein each message (101) is a single-bit message.

14. Terminal device (200) according to one of the claims 10 to 13, wherein each message (101) is one of at least two sequences, and

20 the terminal device (200) is configured to obtain the at least two sequences from the network device (100) or the at least two sequences are preconfigured at the terminal device (200).

15. System of a network device (100) according to one of the claims 1 to 9 and a plurality
25 of terminal devices (200) according to one of the claims 10 to 14, wherein

the network device (100) is configured to send the multicast message (201) to the terminal devices (200), and

each terminal device (200) is configured to send the at least one message (101) having the logical value “false” in the same predetermined resource block as the one or more other
30 terminal devices (200).

16. Method (300) for a network device (100), comprising the steps of

receiving (301) a signal comprising a plurality of superimposed messages (101), wherein each message (101) is sent by one of a plurality of terminal devices (200) and has one of two possible logical values “true” and “false”,

5 determining (302) a logical conjunction or disjunction of the superimposed messages (101) based on a comparison of the received signal with a threshold value.

17. Method (400) for a terminal device (200), comprising the steps of

receiving (401) a multicast message (201) from a network device (100),

10 sending (402) at least a message (!01) having, of two possible logical values “true” and “false”, the logical value “false” to the network device (100), if the multicast message (201) could not be decoded, wherein

the message (101) is sent in a predetermined resource block shared with one or more other terminal devices (200).

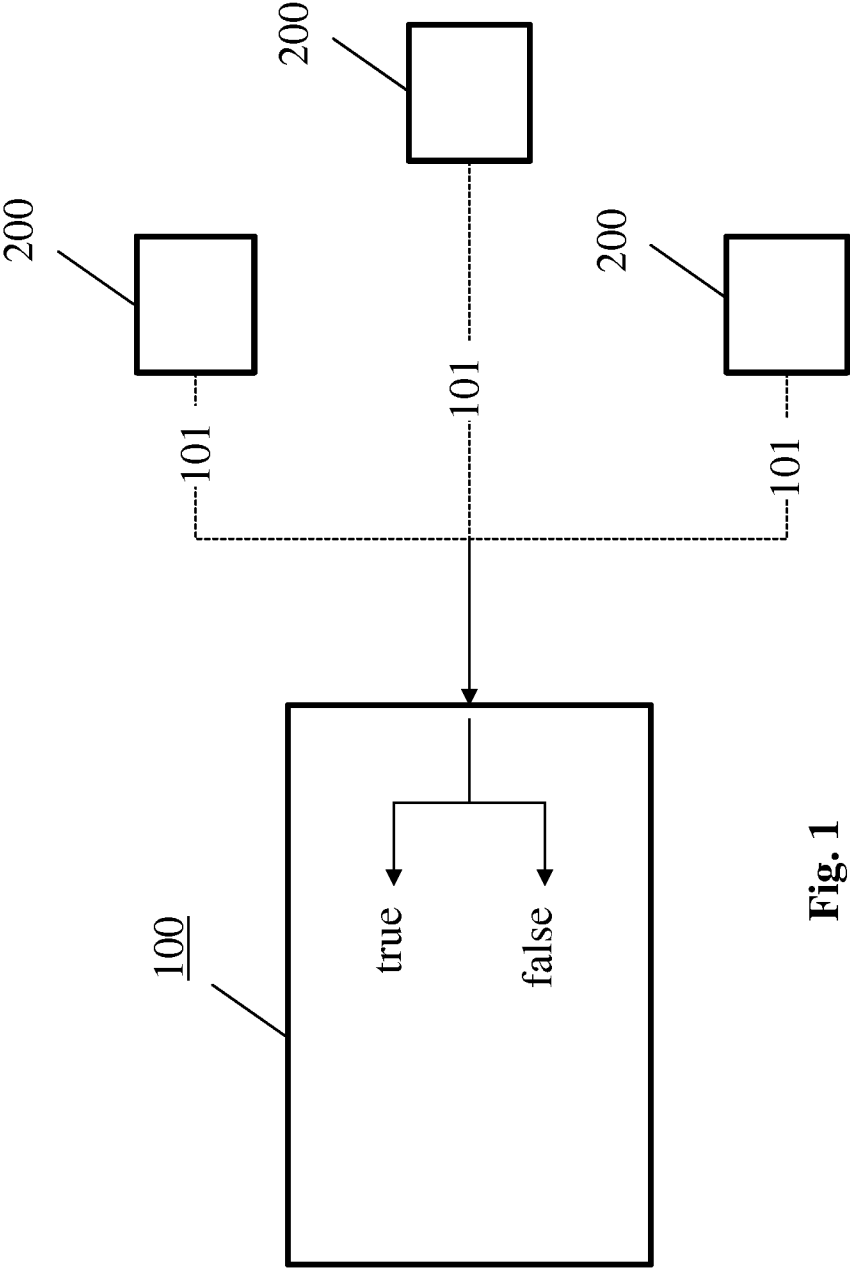


Fig. 1

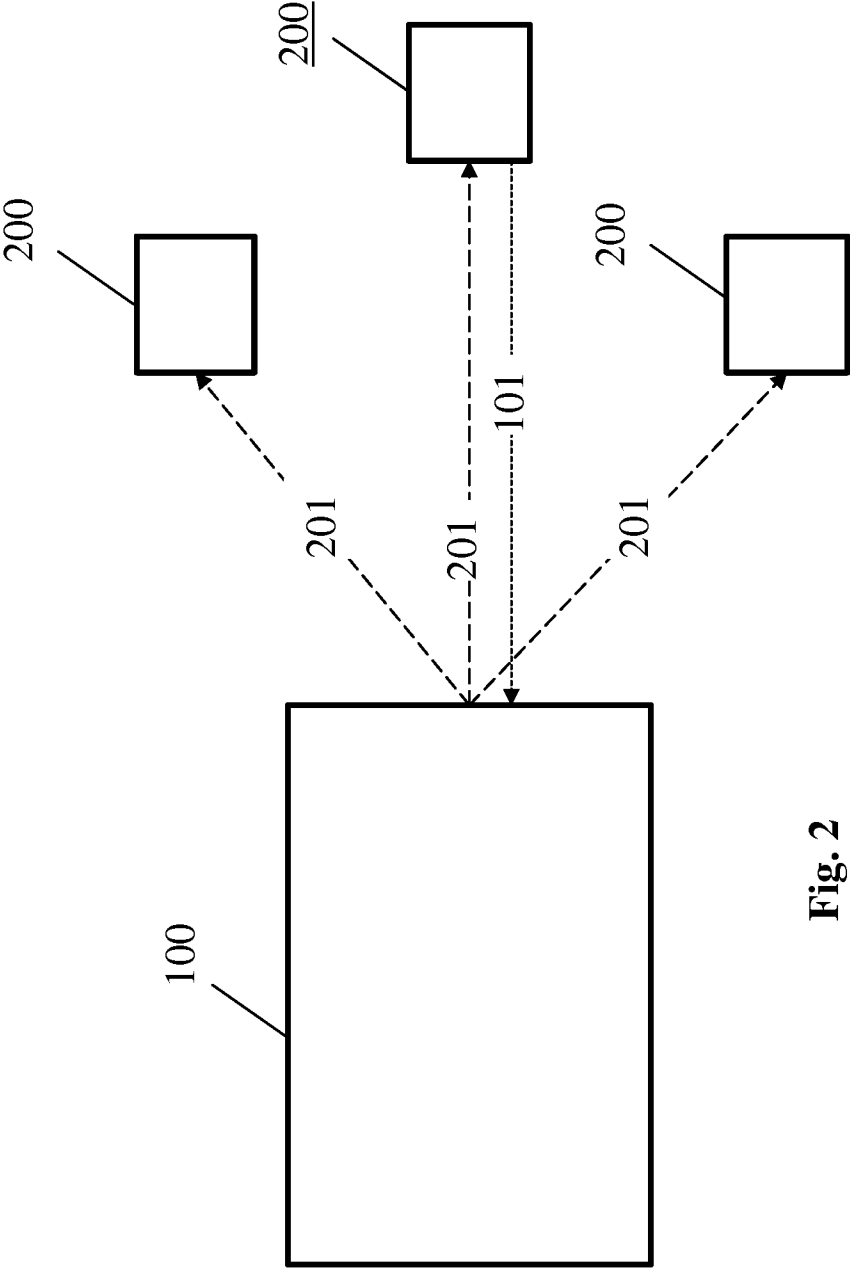
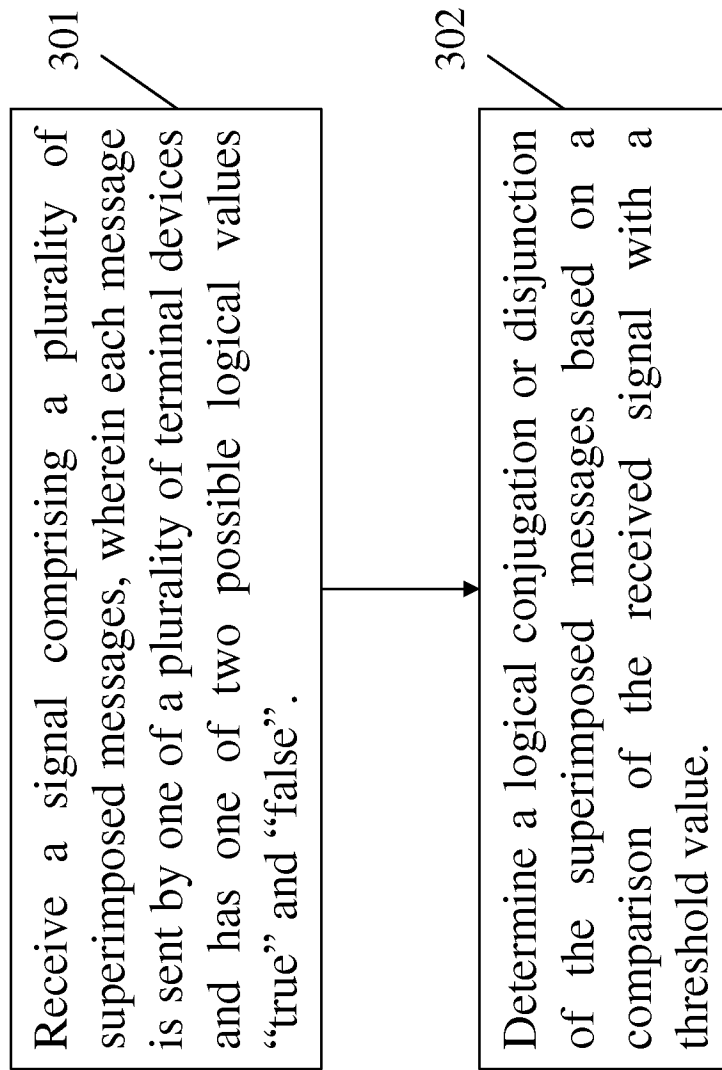
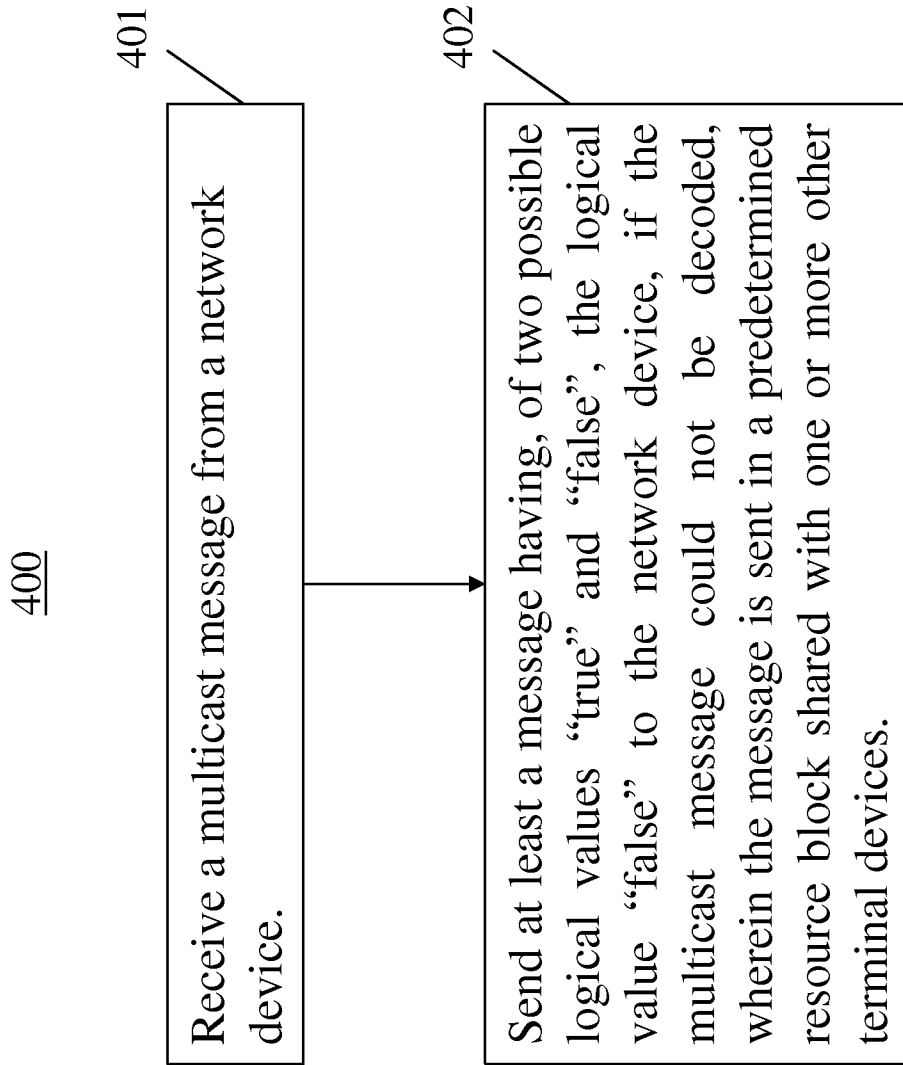


Fig. 2

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300**Fig. 3**

**Fig. 4**

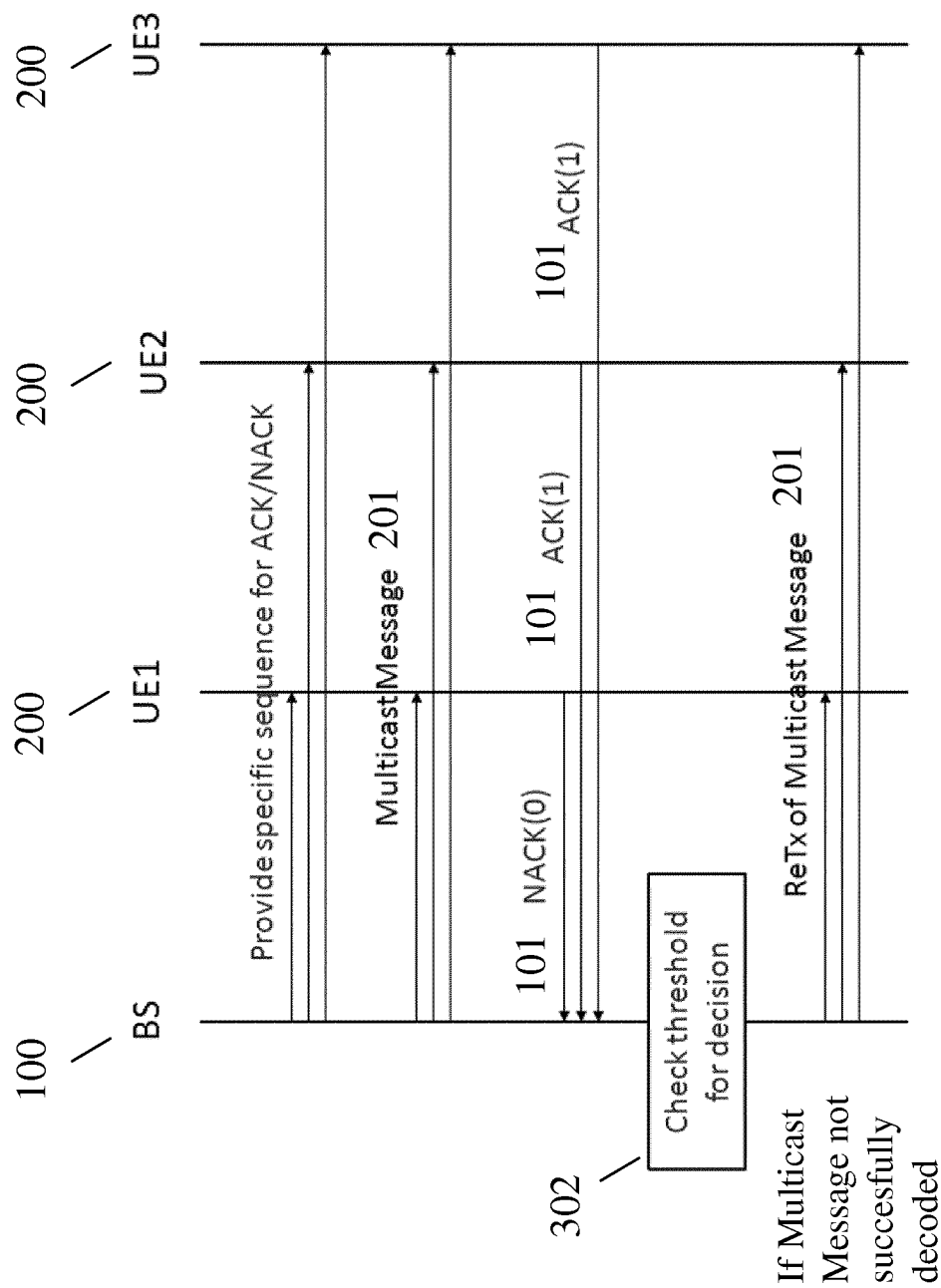


Fig. 5

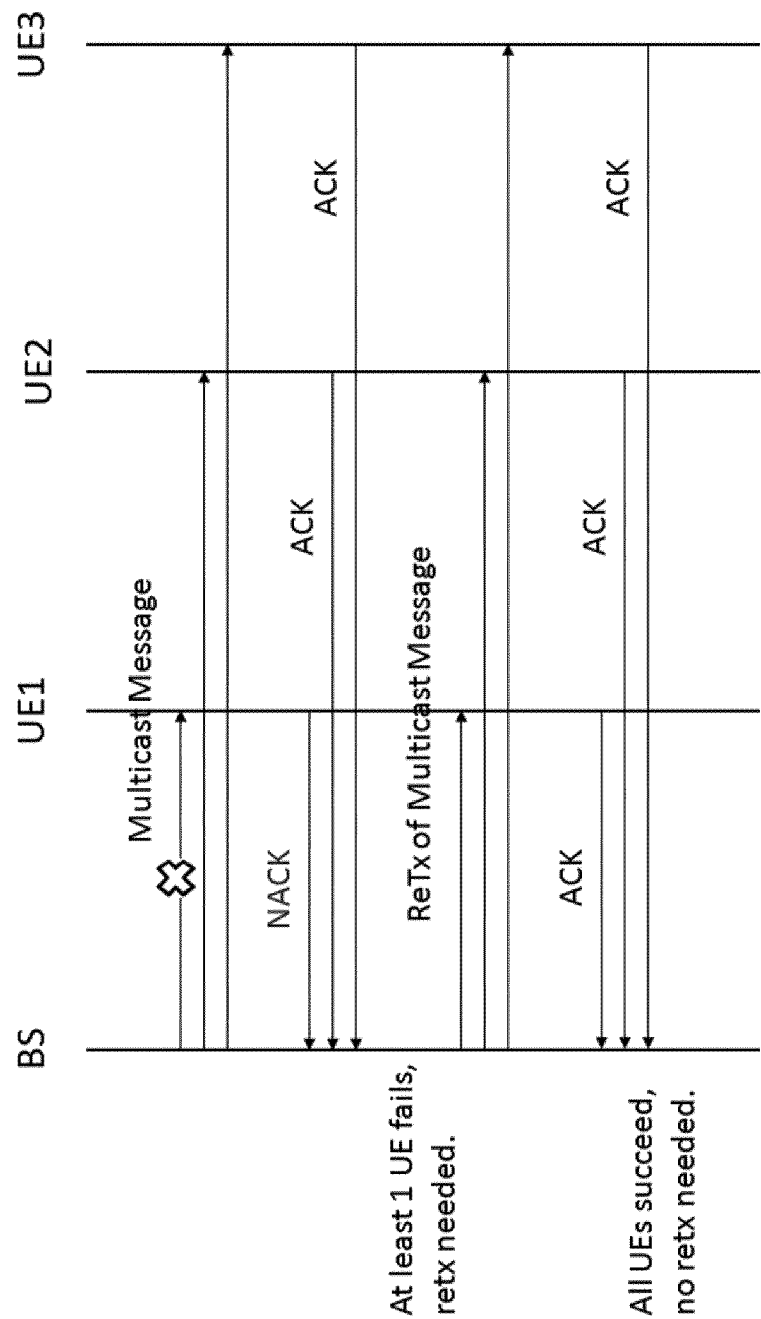


Fig. 6

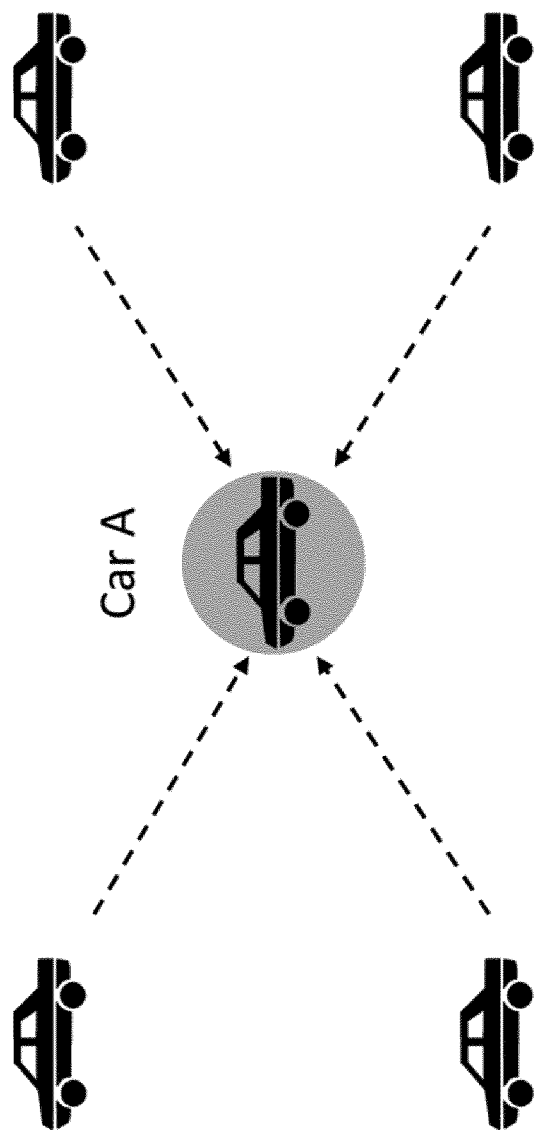


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/064411

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L1/16 H04L1/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/223614 A1 (KUCHIBHOTLA RAVI [US] ET AL) 27 September 2007 (2007-09-27) figures 1, 3, 4 paragraphs [0011], [0017], [0019] paragraphs [0021], [0025] - [0029] -----	1-17
X	US 2014/198710 A1 (HERRMANN CHRISTOPH [DE]) 17 July 2014 (2014-07-17) paragraphs [0038], [0039] paragraphs [0048], [0058], [0171] -----	1,10,16, 17
X	US 2004/166869 A1 (LAROIA RAJIV [US] ET AL) 26 August 2004 (2004-08-26) paragraphs [0019], [0021], [0050] paragraphs [0058] - [0059] ----- -/--	1,10,16, 17

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

21 February 2018

Date of mailing of the international search report

07/03/2018

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/064411

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ZHONGDING LEI ET AL: "WiMax signal detection", MILITARY COMMUNICATIONS CONFERENCE, 2008. MILCOM 2008. IEEE, IEEE, PISCATAWAY, NJ, USA, 16 November 2008 (2008-11-16), pages 1-7, XP031408410, ISBN: 978-1-4244-2676-8 the whole document -----	1-17

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Information on patent family members

International application No

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