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(54) **Title:** METHOD AND SYSTEM FOR SUPPORTING CHANNEL ACCESS OF STATIONS IN A WIRELESS COMMUNICATION NETWORK

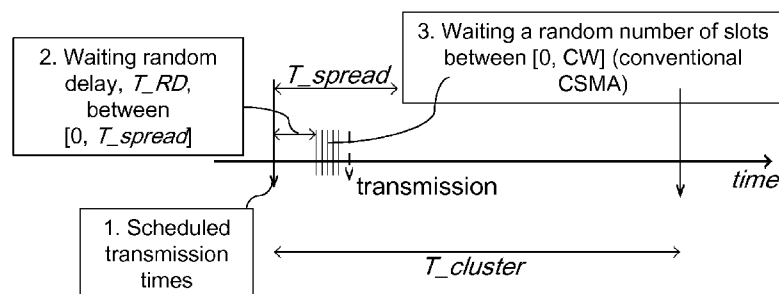


Fig. 2

(57) **Abstract:** A method for supporting channel access of stations in a wireless communication network, wherein said stations form a cluster of synchronized stations that are operated in a synchronous way on the same channel, wherein said cluster has a specific cluster period with scheduled points in time at which said synchronized stations periodically wake up according to a common duty cycle, is characterized in that the stations of said cluster, upon waking up at said scheduled points in time, wait for an individual random delay before accessing and transmitting frames via said channel. Furthermore, a corresponding system for supporting channel access of stations in a wireless communication network and a mobile station for deployment in a wireless communication network are described.



METHOD AND SYSTEM FOR SUPPORTING CHANNEL ACCESS OF STATIONS IN A WIRELESS COMMUNICATION NETWORK

5 The present invention relates to a method and a system for supporting channel access of stations in a wireless communication network, wherein said stations form a cluster of synchronized stations that are operated in a synchronous way on the same channel, wherein said cluster has a specific cluster period with scheduled points in time at which said synchronized stations periodically wake up according to a common duty cycle.

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Furthermore, the present invention relates to a mobile station for deployment in a wireless communication network, comprising means for forming a synchronized cluster of stations that operate in a synchronous way on the same channel, wherein said cluster has a specific cluster period with scheduled points in time at which said synchronized stations periodically wake up according to a common duty cycle.

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Nowadays, wireless communication is in place almost everywhere. Depending on the specific wireless technology being deployed, the wireless communication networks provide a respective infrastructure that typically includes a plurality of geographically distributed access points. Generally, the entire communication among mobile stations is carried out via these access points. However, there is a growing trend of "socializing" mobile wireless communication in a sense that mobile devices are enabled to discover each other and to communicate with each other directly.

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For instance, in the Wi-Fi Alliance a new technology is currently being discussed that is called "Neighbor Aware Networking Wi-Fi" (NAN) or "Social Wi-Fi". The purpose of this technology is to allow any device with a Wi-Fi interface to discover information about its surroundings, thus enabling applications like Proximate Internet, as described in the document "Future of Wireless? The Proximate Internet", <http://www.cedt.iisc.ernet.in/people/kuri/Comsnets/Keynotes/Keynote-Rajiv-Laroia.pdf>.

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The NAN technology should fulfill the following requirements:

1. It should operate in unlicensed spectrum like traditional Wi-Fi.
- 5 2. It should require only a firmware update to current Wi-Fi radios (no hardware changes).
- 10 3. It should enable devices to discover information advertised by their neighbor devices in the background, and with a very low impact on battery duration.

With respect to the last issue, it is to be noticed that a traditional Wi-Fi radio always powered on may yield only 5 hours of battery duration in current smartphones (as described in Ó.R. Helgason, E.A. Yavuz, S.T. Kouyoumdjieva, 15 L. Pajevic, and G. Karlsson, "A mobile peer-to-peer system for opportunistic content-centric networking", in Proceedings of the second ACM SIGCOMM workshop on Networking, systems, and applications on mobile handhelds (MobiHeld '10), ACM, New York, NY, USA, 21-26. 3). Thus, in practice if a current smartphone user charges its phone once a day, it should continue doing so even 20 when NAN operates in the background.

For the sake of simplicity, any communication device that is equipped with a Wi-Fi interface and that uses the NAN technology as described above will be referred to as NAN device hereinafter.

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In order to allow NAN devices to discover information around them in a very energy efficient way, the key technical concept is synchronization. Accordingly, NAN devices will try to synchronize to a common duty cycle, thereby forming a cluster of devices that wake up and transmit data concurrently in a synchronous 30 way. All NAN devices of a cluster will thus periodically wake up to advertise information about them. This idea is illustrated in Fig. 1 that schematically depicts two smartphones STA1 and STA2 that operate as NAN devices. Both devices operate in the same cluster, i.e. they wake up in a synchronous way, quickly advertise their information via a common channel (ch1, ch6, or ch11, respectively)

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and go back to sleep/doze mode to save power. In order to be energy efficient typical duty cycles (duty cycle being the ratio between the time the station is awake over the cluster period) around 5~10% are expected to be realized in real deployment scenarios.

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Generally, in a synchronous wireless technology as the one described above, channel access might become critical. This problem can be stated in the following terms: If all devices try to access the channel at the same time, since they are synchronized, a lot of collisions will occur and devices will not be able to receive all the frames transmitted by its neighbors, which in NAN are referred to as Announcement frames.

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In addition, there are certain practicalities that make solving the problem of channel access even more challenging, like the fact that NAN should be a firmware upgrade on current Wi-Fi radios. This means that many of the traditional Wi-Fi channel access functions that are implemented in hardware will have to be reused in NAN. These hardware functions relate to the CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) channel access mechanism where stations transmit directly if they sense the channel free, but compute a random delay between 0 and CW (Contention Window) time slots when the channel is busy. The value of CW can usually be tuned from the firmware.

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Thus, a sensible way to address the channel access problem in NAN, which is extensively documented in the literature (for instance in Gardar Hauksson and Murat Alanyali: "Wireless medium access via adaptive backoff: Delay and loss minimization", available at http://iss.bu.edu/alanyali/Publications/project_report1.pdf), is to adjust the value of CW. For instance if one expects a lot of devices contending to access the channel at the same time, CW would be configured to have a large value, otherwise CW would be configured with a low value. This approach though has a problem in practice, which arises from the fact that legacy Wi-Fi devices (i.e. non NAN devices) operate with CW values that are small (typically CW=15). This means that when NAN devices operate in the same channel than legacy Wi-Fi devices, which will be a very common case given the ubiquity of Wi-Fi, NAN devices will experience a very low priority (because of the

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larger CW) as compared to the legacy devices. This lower priority in accessing the channel can result in a decreased battery performance and in fewer Announcement frames received by NAN devices.

- 5 It is therefore an object of the present invention to improve and further develop a method and a system of the initially described type for supporting channel access of stations in a wireless communication network in such a way that channel access performance is enhanced.
- 10 In accordance with the invention, the aforementioned object is accomplished by a method comprising the features of claim 1. According to this claim such a method is characterized in that
- the stations of said cluster wake up at said scheduled points in time,
 - before accessing the channel said stations compute an individual random
 - 15 delay and defer their access to the channel by a time equal to the computed random delay, and
 - after expiration of said individual access delay, said stations access the channel using a conventional channel access mechanism.
- 20 Furthermore, the aforementioned object is accomplished by a system comprising the features of claim 12. According to this claim such a system is characterized in that the stations of said cluster are configured
- to wake up at said scheduled points in time,
 - to compute an individual random delay and to defer their access to the
 - 25 channel by a time equal to the computed random delay, and
 - after expiration of said individual access delay, to access the channel using a conventional channel access mechanism.
- 30 Still further, the aforementioned object is accomplished by a mobile station comprising the features of claim 14. According to this claim such a mobile station is characterized in that it is configured
- to wake up at said scheduled points in time,
 - to compute an individual random delay and to defer its access to the channel by a time equal to the computed random delay, and

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- after expiration of said individual access delay, to access the channel using a conventional channel access mechanism.

According to the invention it has been recognized the number of collisions can be
5 minimized, while at the same time keeping the energy consumption of the stations
as low as possible, by introducing for the stations an individual random
transmission delay before each transmission. This means that each station inserts
a random delay before accessing the channel at the synchronized access times,
10 which allows the stations to minimize collisions without the need of increasing their
CW. As a result, the present invention significantly increases the amount of
received information and thus enhances channel access performance, since it
allows a large number of synchronized stations to access the channel with
reduced collision probabilities. The present invention differs from the state of the
15 art by minimizing the collisions without having to increase the Contention Window
parameter. As previously explained, this has the advantage of allowing NAN
devices to compete with the same priority than legacy devices. In this regard it is
important to note that finding legacy devices will be a very common situation in
practice, in particular because the NAN technology will operate in unlicensed
20 spectrum, e.g. the 2.4 GHz band, which is heavily used by legacy Wi-Fi devices.

It is to be noted that the present invention is generic and can be applied to any
wireless technology where devices operate in a cluster building way, such that
they wake up and transmit at scheduled and synchronous points in time.
Nonetheless, the advantages of the invention will be particularly prevalent in a Wi-
25 Fi infrastructure with synchronized NAN clusters. Here, compared to using, e.g.,
pure CW tuning as currently available in the state of the art, a much more efficient
operation can be achieved, both in terms of reception characteristic and energy
consumption. In this regard is important to note that energy efficiency is critical to
technologies like NAN that target use cases requiring always on connectivity.

30 According to a preferred embodiment the stations of the cluster compute their
individual random delay as a bounded random delay between 0 and a specific
time period T_{spread} .

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In an embodiment of the present invention T_{spread} is a value common to all devices using this technology. Advantageously, this value of T_{spread} may be dimensioned according to the expected number of devices operating in a cluster and their power requirements.

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In a more advanced embodiment, in order to minimize the delay that needs to be inserted, the time period T_{spread} may be configured in an adaptive way. For instance, an adaptive configuration of the time period T_{spread} may be performed depending on the load that a given station is sensing in its neighborhood, in particular depending on the load and/or the number of competing stations a given station observes on the channel. In other words, the random waiting time may be adjusted according to the number of neighboring synchronized devices, or the amount of congestion sensed in the channel, which may vary over time. By implementing such adaptation, a large number of stations is allowed to operate in a synchronized transmission duty cycle, thereby increases battery life of each of the stations.

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With respect to collecting information on the load on the channel reliably and efficiently, it may be provided that the stations of a cluster continuously track the number of frames that they observe in their neighborhood, or the time required to transmit a frame in the channel. For instance, this can be realized in such a way that the stations of the cluster count the number of Announcement frames that they observe on the channel every time they wake up, or measure the time elapse from the time they prepare a frame for transmission until the frame is successfully transmitted.

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Based on the discovered load information, before transmitting, a station may derive the value of the time period T_{spread} as a function of the number of Announcement frames it has observed, or congestion sensed in the channel, thereby applying the following logic: 1) If the number of observed Announcement frames, or channel congestion, is large, i.e. there is high load, T_{spread} should be big to minimize collisions, and 2) if, on the other hand, the number of observed Announcement frames, or channel congestion, is small, i.e. there is light load, T_{spread} should be small to minimize the duty cycle and hence save battery. For

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instance, following the above logic the stations of a cluster may configure the time period T_{spread} in such a way that the time period T_{spread} used in a given duty cycle is proportional to the number of Announcement frames, or channel congestion, observed in the previous duty cycles.

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In a somehow more sophisticated embodiment, it may be provided that a tunable positive proportional factor is employed for the calculation of the time period T_{spread} . By this means a safe margin is introduced into the estimation in order to avoid using too small values for the time period T_{spread} .

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According to a preferred embodiment the duration of the Announcement frames is taken into consideration for the calculation of the time period T_{spread} , since the duration also represents a measure of the channel load. In particular, it may be provided that an average duration of the Announcement frames is calculated, that is used to adjust the value of T_{spread} .

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After the random delay, T_{RD} , is computed between 0 and a duration T_{spread} , it may be provided that the stations of the cluster perform channel access by means of using conventional Wi-Fi channel access mechanism, in particular CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) with a given contention window (CW) that is known to all stations operating in the cluster.

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There are several ways how to design and further develop the teaching of the present invention in an advantageous way. To this end, it is to be referred to the patent claims subordinate to patent claims 1 and 12 on the one hand, and to the following explanation of a preferred example of an embodiment of the invention illustrated by the drawing on the other hand. In connection with the explanation of the preferred example of an embodiment of the invention by the aid of the drawing, generally preferred embodiments and further developments of the teaching will be explained. In the drawings

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Fig. 1 schematically illustrates an example of a synchronized cluster of mobile stations according to prior art,

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- Fig. 2 schematically illustrates a transmission process of a synchronized NAN station in accordance with an embodiment of the present invention,
- 5 Fig. 3a/b schematically illustrate the results of a simulative study evaluating the channel access performance in terms of successfully received Announcement frames of a method for supporting channel access in accordance with embodiment of the present invention,
- 10 Fig. 4a/b is a diagram illustrating the duration of scanning attempts performed by a mobile station in accordance with the present invention, and
- Fig. 5 is a diagram illustrating the energy spent by a mobile station in scanning attempts performed in accordance with the present invention.
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Fig. 2 schematically illustrates an embodiment of the present invention. Although the embodiment is related to the NAN technology, it is once again noted that the present invention is not restricted thereto, but can be applied to any other wireless technology where devices operate in a synchronous way on the same channel.

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In the context of Fig. 2 it is assumed that a number of stations in a Wi-Fi network form a cluster of synchronized stations that wake up and transmit their Announcement frames according to a common duty cycle, as depicted in Fig. 2 by the vertical arrows that indicate the scheduled transmission times and by cluster period $T_{cluster}$ between each two subsequent transmission times. In accordance with the embodiments of the present invention after the scheduled wake up time a station computes a random delay, referred to as T_{RD} , between 0 and a value T_{spread} . In particular, according to the illustrated embodiment, the detailed steps that a station takes before accessing the channel are:

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1. The station wakes up at the scheduled time, which is synchronized with all other stations in the cluster.

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2. Instead of transmitting directly, the station computes a random delay, referred to as T_{RD} , between 0 and T_{spread} .
3. After a time equal to T_{RD} the station makes a channel access using the traditional Wi-Fi channel access mechanism, i.e. CSMA/CA with a given contention window (CW), like legacy Wi-Fi stations, e.g. CW=15.

By randomizing channel access as described above the collision probability will be significantly decreased. However, in order to enjoy a small duty cycle and be energy efficient it is furthermore desirable to have $T_{spread} \ll T_{cluster}$, where $T_{cluster}$ is the time between consecutive wake up events of devices in the NAN cluster. To this end, an appropriate configuration of the value of T_{spread} in the previous scheme may be performed. In this regard it is important to note that if T_{spread} is too small, there will be too many collisions and few Announcement frames will be received. On the other hand, if T_{spread} is too large, the station will pay a penalty in terms of battery. Therefore, a simple embodiment of the present invention can use a T_{spread} value that has been configured a priori having in mind an expected number of stations operating in a NAN cluster. In addition, in a more advanced embodiment the value of T_{spread} is configured in an adaptive way, in particular according to the number of competing stations, or channel congestion, that a given NAN station observes in the channel. According to a specific embodiment the advanced method is implemented in the following way:

A NAN device continuously tracks the number of frames that it observes in its neighborhood. This can be trivially done, for instance, by counting the number of Announcement frames that it observes every time that it wakes up. This number of Announcement frames is kept in a variable N_{fr} . Then, before transmitting, the NAN station derives the value of T_{spread} as a function of its variable N_{fr} , following this logic:

- 1) If N_{fr} is large, i.e. there is high load, T_{spread} should be large to minimize collisions, and
- 2) if N_{fr} is small, i.e. there is light load, T_{spread} should be small to minimize the duty cycle and hence save battery.

- 10 -

According to a specific embodiment the previous rule is implemented as follows:

$$T_{spread}(n) = \beta * N_{fr}(n-1) * Ann_Frame_Duration,$$

5 where n is an integer that denotes the actual cluster period, $N_{fr}(n-1)$ is the number of Announcement frames that were received in the previous cluster period, where $Ann_Frame_Duration$ denotes the average duration of an Announcement frame, and where $\beta > 1$ is a constant used to have a safe margin in the estimation (i.e. to avoid using a too small T_{spread}).

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Figs. 3-5 illustrate the results of a simulation study that evaluates the performance of embodiments of the present invention and compares it with a solution of only adjusting the CW (Contention Window) parameter. The underlying simulation scenario consists of NAN stations moving randomly at pedestrian speeds in a 500m x 500m area, which could represent for instance to a typical city center. Further, the simulation scenario considers that these stations implement the NAN technology and become synchronized in clusters. Thus, in this context the channel access performance is studied by looking at: 1) Goodput, or percentage of successfully received Announcement frames, and 2) Duty cycle, which represents the impact of channel access into battery consumption.

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The evaluation is started by analyzing the effect of using different T_{spread} and CW values. However in this initial experiment the stations use a fixed T_{spread} , i.e. T_{spread} is not dynamically adapted. The corresponding results are depicted in Fig. 3a, which illustrates the channel access performance for the following parameter combinations, when the number of contending stations is varied between 10 and 100:

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- $CW = 15$ (lines with circles) and $CW = 1023$ (lines with arrows);
- 30 - $T_{spread} = 0$ ms, 50ms, 100ms and 200ms (signaled with an arrow in the graphs).

What can be seen from Fig. 3a is the following:

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$CW=15$ without spreading is not viable since this configuration yields too few received Announcement frames, which is in any case below 50% and, in case of high number of stations, even drops to a value around 20%. Increasing the contention window to a value $CW=1023$ improves performance (~80% received
 5 Announcements frames), however, this configuration will not protect against legacy Wi-Fi traffic, as will be described in some more detail further below.

As can be seen, spreading load as suggested by the present invention (i.e. $T_{spread} > 0$) improves the percentage of successfully received Announcement
 10 frames in a very significant way. For instance, in case of $T_{spread} = 100$ ms that are around 90% successfully received Announcement frames, while this value is increased even more (to a value around 95%) in case of $T_{spread} = 200$ ms. In addition, when load spreading is used, the value of CW does not have much impact, so one can use a small CW that will protect NAN devices against legacy
 15 devices.

In Fig. 3b, which illustrates the channel access performance in terms of the average duty cycle for the same parameter combinations as Fig. 3a, one can see the trade-off of introducing a random delay before transmission, i.e. spreading: the
 20 duty cycle increases with increasing T_{spread} . Notice that the duty cycle is signaled for two possible cluster periods $T=1$ second and $T=10$ second. The lowest graph depicted in Fig. 3b illustrates the idea case in which all frames are scheduled after SIFS (Short Interframe Spacing). The achieved results show that with $T=10$ seconds the obtained duty cycles would still be feasible (<2.5%), but
 25 with $T=1$ second they would not be (<25%).

In the following, the performance of an adaptive spreading approach will be described in more detail. Specifically, the evaluation relates to the adaptive spreading approach that uses the following adaptation rule:

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$$T_{spread}(n) = \beta * N_{fr}(n-1) * Ann_Frame_Duration,$$

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as described already above in connection with Fig. 2. It is to be noted that the above rule includes parameter, β , which can be tuned. Therefore, the performance with various values for β will be studied hereinafter.

5 Fig. 4 shows that by using adaptive spreading intervals and the right value for β (which in practice can be obtained by simulations) reasonable goodputs (i.e. percentage of successfully received Announcement frames) can be achieved for both $CW=15$ (lines with circles) and $CW=1023$ (lines with arrows), see Fig. 4a. Generally, the higher the value for β , i.e. the stronger the spreading, the higher
10 is the percentage of successfully received Announcement frames. In addition, as can be obtained from Fig. 4b, the biggest advantage of the adaptive scheme is that now the duty cycle is not flat (like in the non-adaptive scenario illustrated in corresponding Fig. 3b), but is small when there are not many stations in the network, and it increases when the number of stations increases. In addition, it can
15 be noted that according to embodiments of the present invention enhanced adaptation schemes could make the value of β adaptive to network conditions.

Finally, the evaluation is being concluded by showing the negative effects of having a large CW , e.g. $CW=1023$ in the presence of legacy Wi-Fi stations. To
20 this end, Fig. 5 depicts the instantaneous duty cycle experienced by NAN stations in a synchronized cluster over time. In the simulation scenario, at two points in time though, around 500 seconds and 800 seconds, some legacy Wi-Fi stations download a FTP file through an Access Point with $CW=15$. It can be seen that when that happens, if the NAN stations use $CW=1023$ (upper line with crosses)
25 their duty cycle immediately increases, because they have to defer to the legacy traffic. However, if NAN stations use $CW=15$ (lower line with diamonds), like legacy stations, their duty cycles continue to be very similar because they compete with legacy on the same priority. Therefore, using $CW=1023$ to decrease collision probability in NAN, as solutions in the state of the art like (Gardar Hauksson and
30 Murat Alanyali: "Wireless medium access via adaptive backoff: Delay and loss minimization", available at http://iss.bu.edu/alanyali/Publications/project_report1.pdf) would do, is not as good in practice as solutions in that insert a random delay before accessing the channel according to embodiments of the present invention.

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Many modifications and other embodiments of the invention set forth herein will come to mind the one skilled in the art to which the invention pertains having the benefit of the teachings presented in the foregoing description and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to
5 the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

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Claims

1. Method for supporting channel access of stations in a wireless communication network,
5 wherein said stations form a cluster of synchronized stations that are operated in a synchronous way on the same channel,
 wherein said cluster has a specific cluster period with scheduled points in time at which said synchronized stations periodically wake up according to a common duty cycle,
10 c h a r a c t e r i z e d i n t h a t
 - the stations of said cluster wake up at said scheduled points in time,
 - before accessing the channel said stations compute an individual random delay and defer their access to the channel by a time equal to the computed random delay, and
 - 15 - after expiration of said individual access delay, said stations access the channel using a conventional channel access mechanism.
2. Method according to claim 1, wherein the stations of said cluster compute said individual random delay as a bounded delay between 0 and a specified time
20 period T_{spread} .
3. Method according to claim 2, where said time period T_{spread} has a pre-defined value which is known by all the stations.
- 25 4. Method according to claim 2 or 3, wherein said time period T_{spread} is configured in an adaptive way.
5. Method according to claim 2 or 4, wherein an adaptive configuration of said time period T_{spread} is performed depending on the load and/or the number of
30 competing stations a given station observes on said channel.
6. Method according to any of claims 1 to 5, wherein the stations of said cluster track the level of congestion that they observe on said channel.

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7. Method according to any of claims 1 to 6, wherein the stations of said cluster count the number of Announcement frames that they observe on said channel every time they wake up.

5 8. Method according to claim 6 or 7, wherein the stations of said cluster configure said time period T_{spread} in such a way that said time period T_{spread} used in a given duty cycle is adjusted according to the number of Announcement frames, or the level of congestion, observed in the previous duty cycles.

10 9. Method according to any of claims 2 to 8, wherein a tunable positive proportional factor is employed for the calculation of said time period T_{spread} .

10. Method according to any of claims 7 to 9, wherein the duration of said Announcement frames is taken into consideration for the calculation of said time
15 period T_{spread} .

11. Method according to any of claims 1 to 10, wherein the stations of said cluster perform channel access by means of using conventional Wi-Fi channel access mechanism, in particular CSMA/CA (Carrier Sense Multiple
20 Access/Collision Avoidance) with a given contention window.

12. System for supporting channel access of stations in a wireless communication network, in particular for executing a method according to any of claims 1 to 11,

25 wherein said stations form a cluster of synchronized stations that are operated in a synchronous way on the same channel,

wherein said cluster has a specific cluster period with scheduled points in time at which said synchronized stations periodically wake up according to a common duty cycle,

30 characterized in that the stations of said cluster are configured

- to wake up at said scheduled points in time,
- to compute an individual random delay and to defer their access to the channel by a time equal to the computed random delay, and

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- after expiration of said individual access delay, to access the channel using a conventional channel access mechanism.

13. System according to claim 12, wherein said cluster of synchronized stations
5 is a synchronized NAN cluster.

14. Mobile station for deployment in a wireless communication network,
comprising:
means for forming a synchronized cluster of stations that operate in a
10 synchronous way on the same channel, wherein said cluster has a specific cluster
period with scheduled points in time at which said synchronized stations
periodically wake up according to a common duty cycle,
c h a r a c t e r i z e d i n that the station is configured
- to wake up at said scheduled points in time,
15 - to compute an individual random delay and to defer its access to the
channel by a time equal to the computed random delay, and
- after expiration of said individual access delay, to access the channel using
a conventional channel access mechanism.

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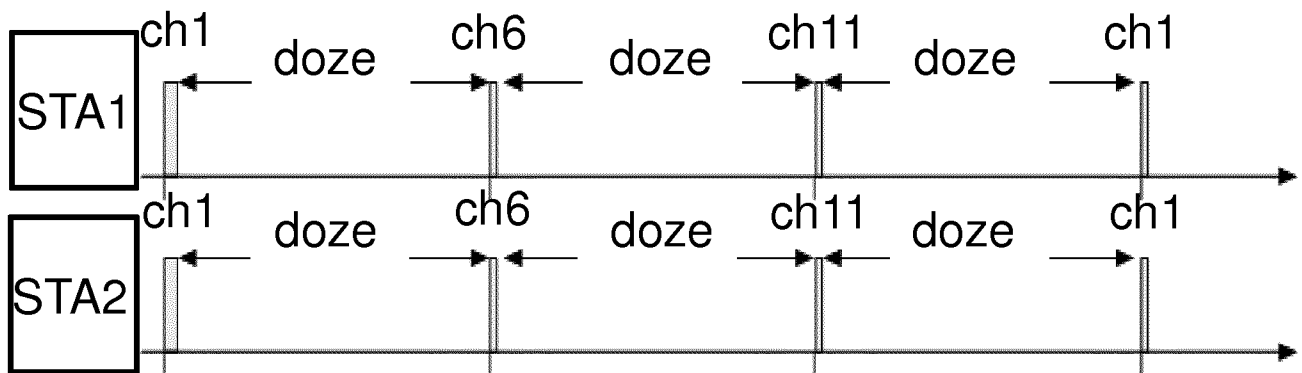


Fig. 1
Prior Art

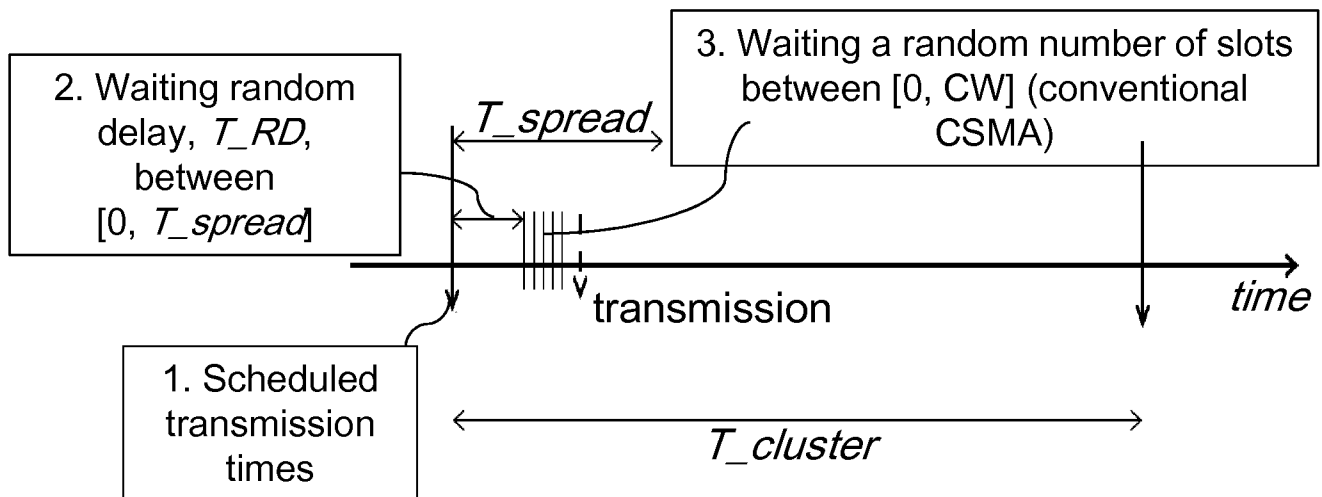


Fig. 2

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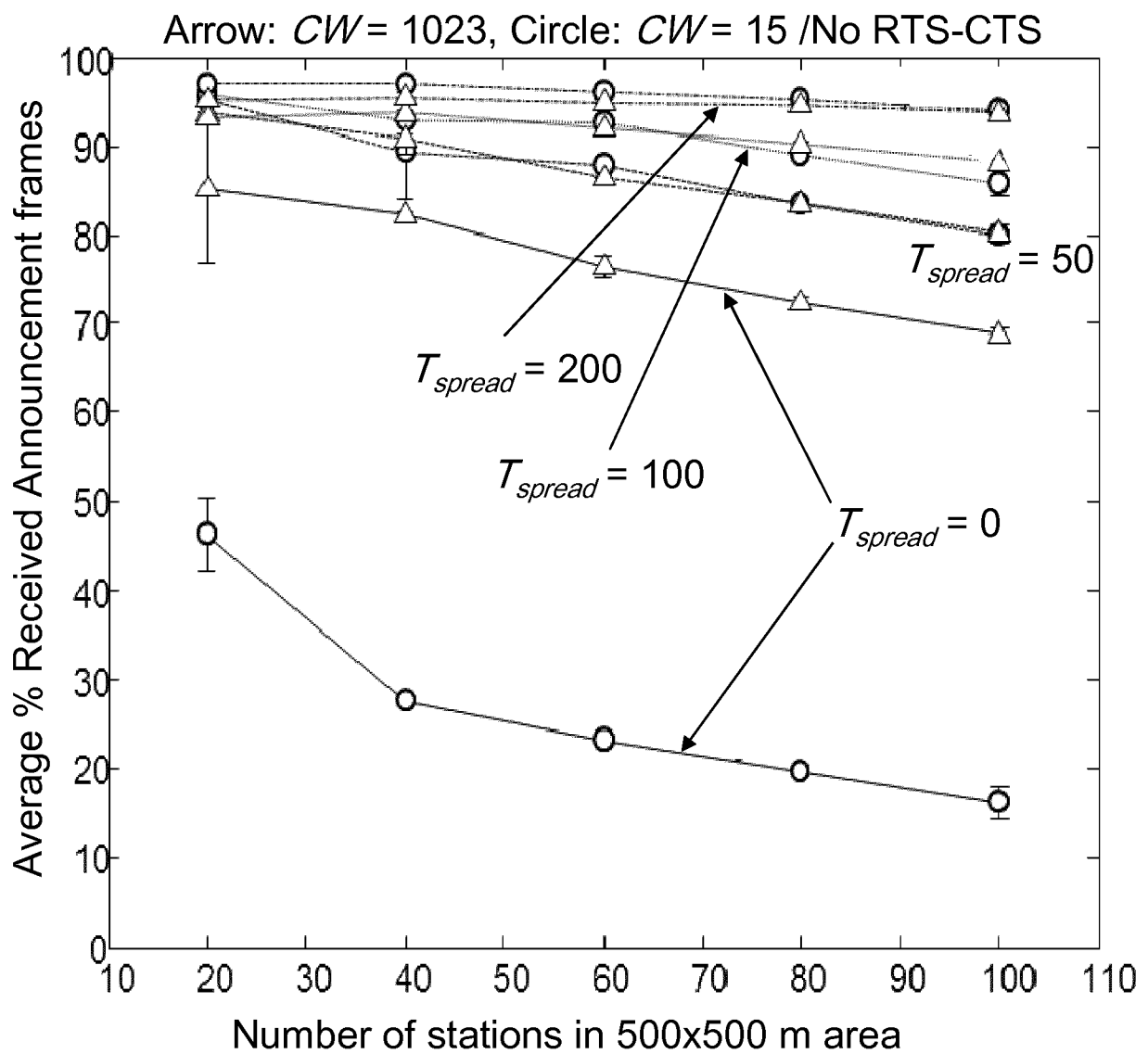


Fig. 3a

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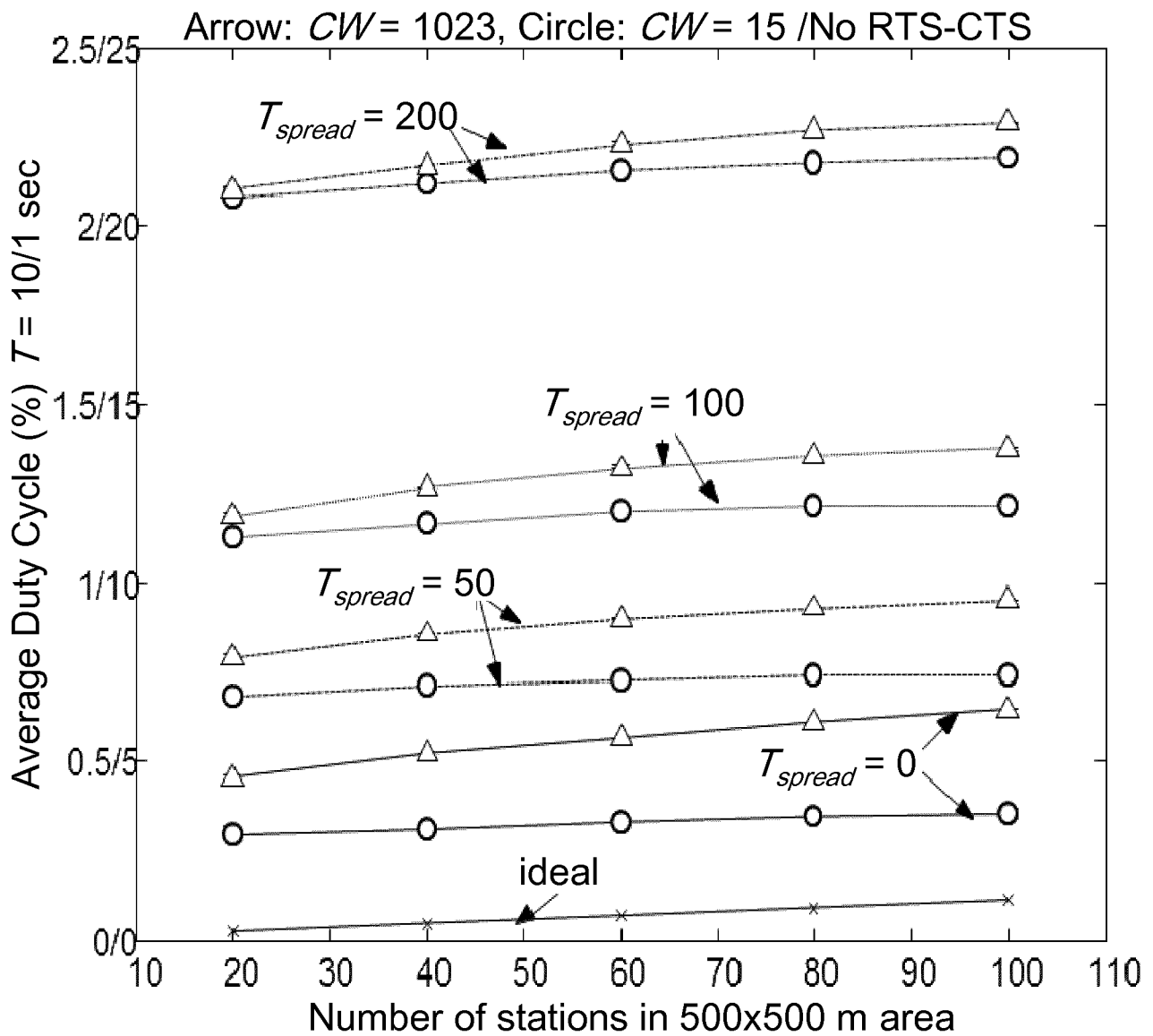


Fig. 3b

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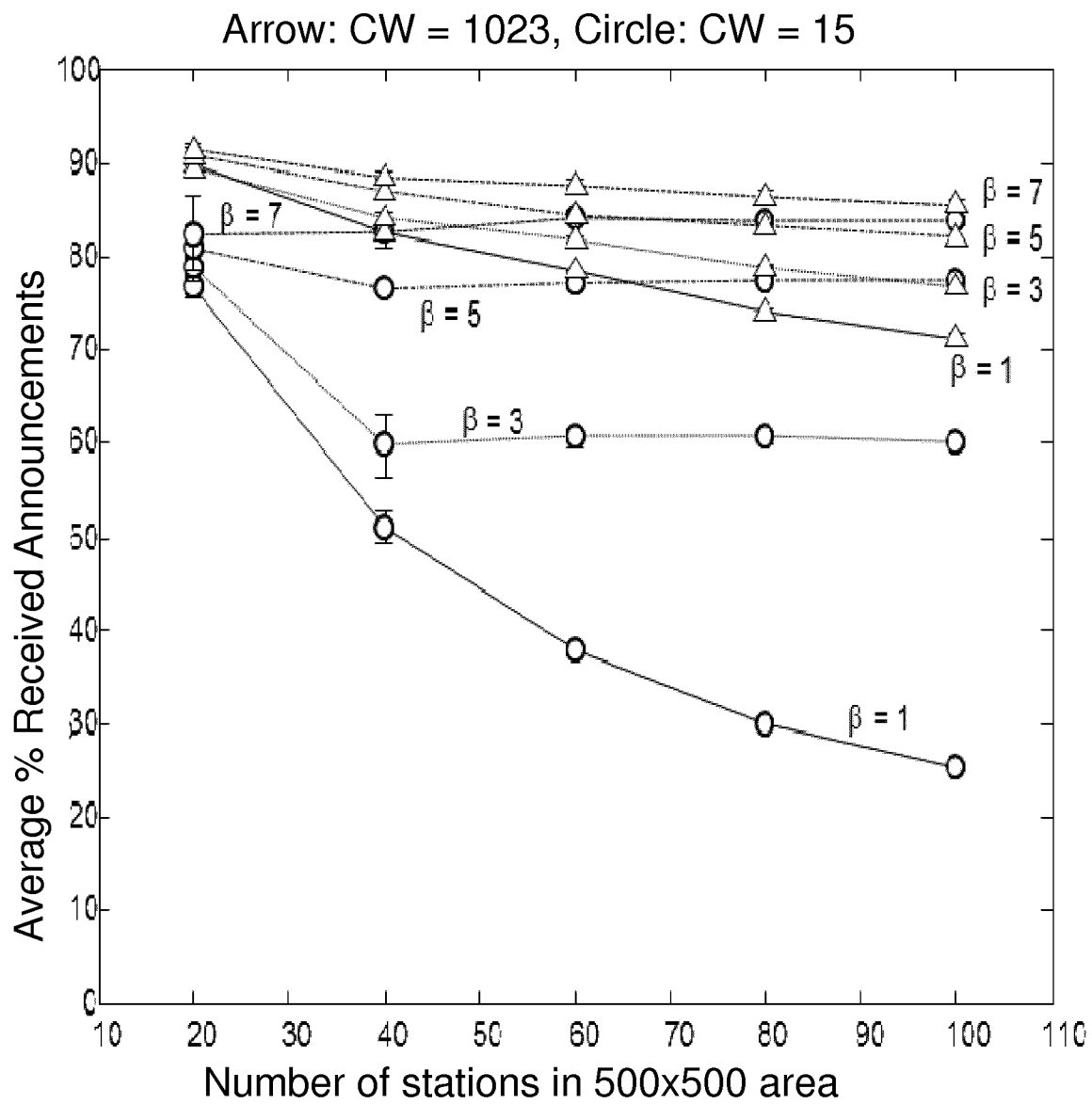


Fig. 4a

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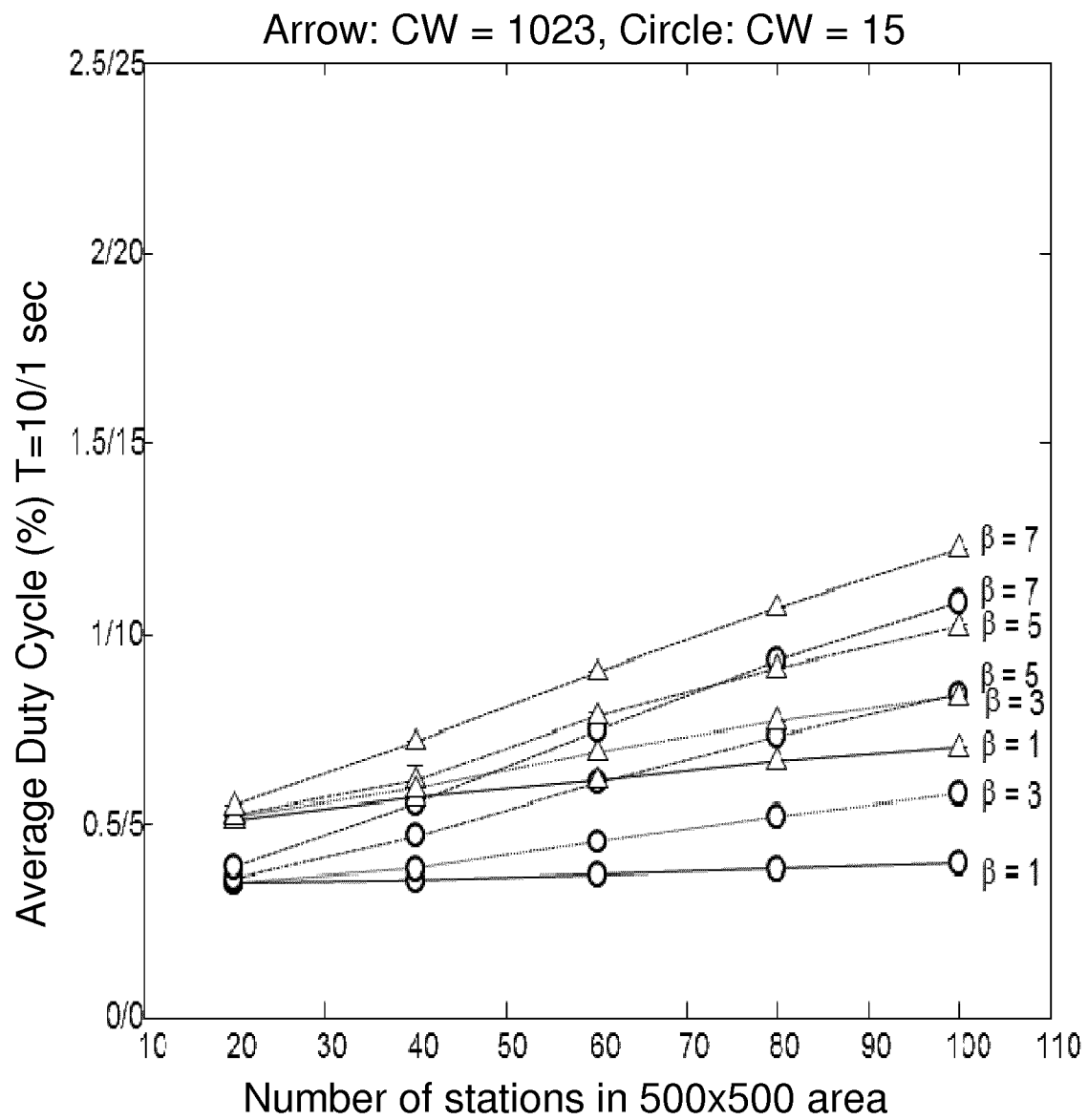


Fig. 4b

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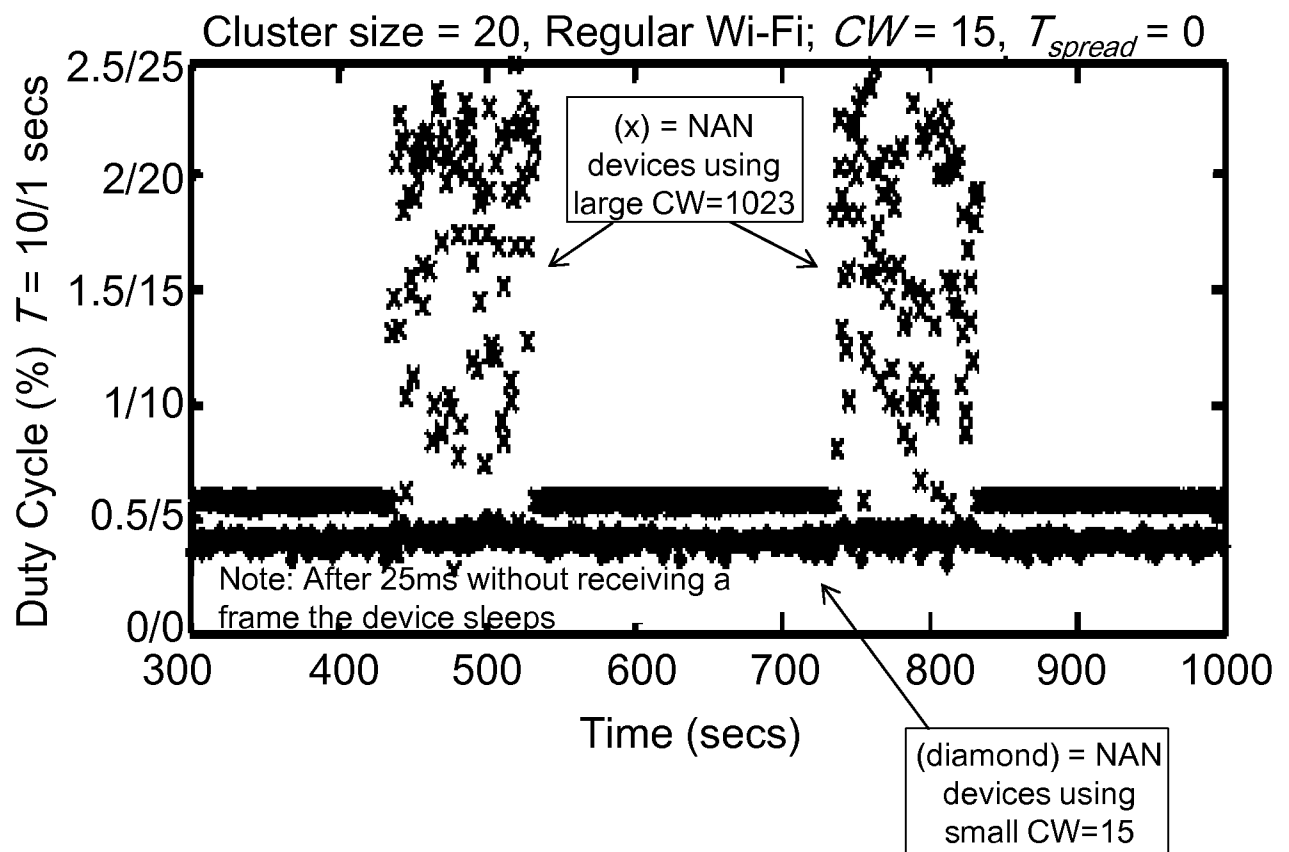


Fig. 5