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## (12) United States Patent
### Maltseff et al.

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(54) **STOCHASTIC COMMUNICATION PROTOCOL METHOD AND SYSTEM FOR RADIO FREQUENCY IDENTIFICATION (RFID) TAGS BASED ON COALITION FORMATION, SUCH AS FOR TAG-TO-TAG COMMUNICATION**

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(52) **U.S. Cl.** .................................... **370/312**; 340/310.1
(58) **Field of Classification Search** ................... 370/312
See application file for complete search history.

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(57) **ABSTRACT**

Data carriers (such as RFID tags) are formed into clusters of data carriers. Each cluster has at least one bridge data carrier that can communicate with a bridge data carrier of another cluster, thereby allowing data carriers in each cluster to communicate directly or indirectly with each other using a stochastic communication protocol method. Direct tag-to-tag communication capability is provided between data carriers in each cluster and/or between clusters. The data carriers can backscatter and modulate a carrier wave from a source, thereby using the backscattered and modulated carrier wave to convey data to each other.

39 Claims, 6 Drawing Sheets



CLUSTER 1

CLUSTER 2

CLUSTER 3
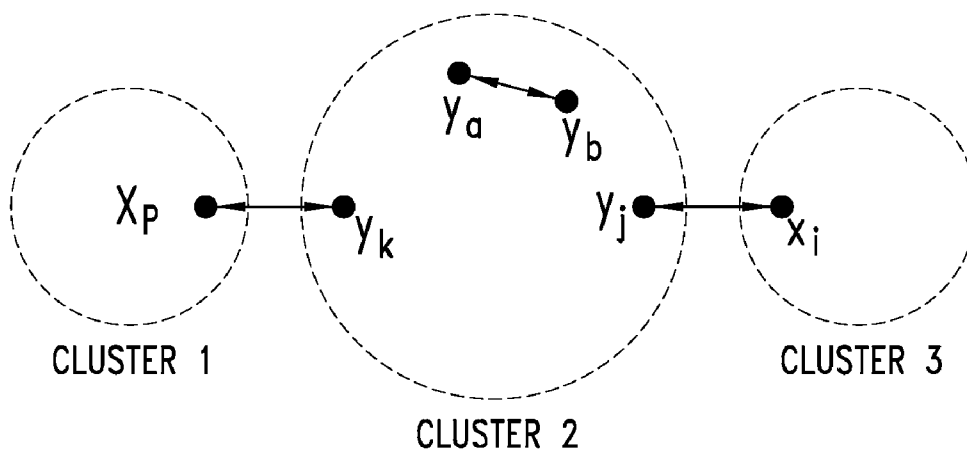
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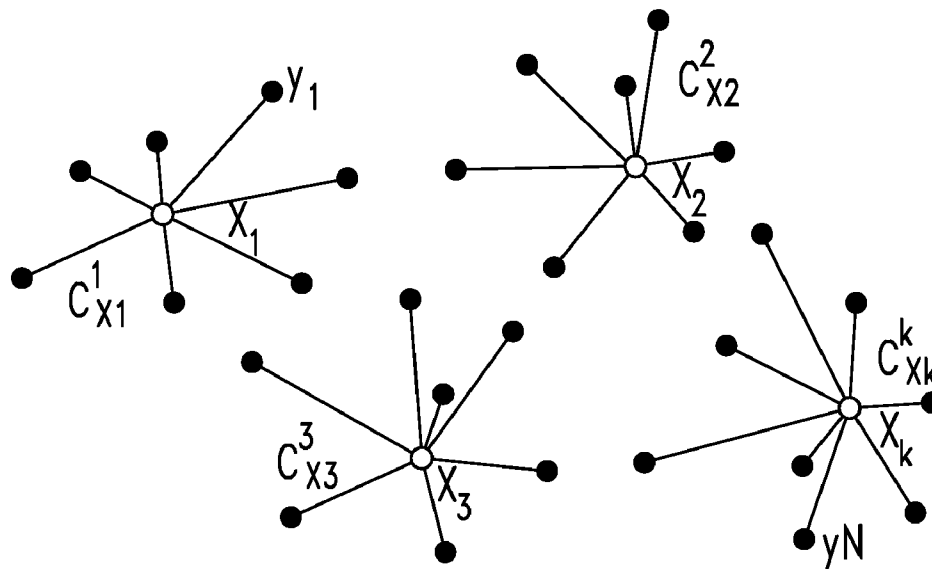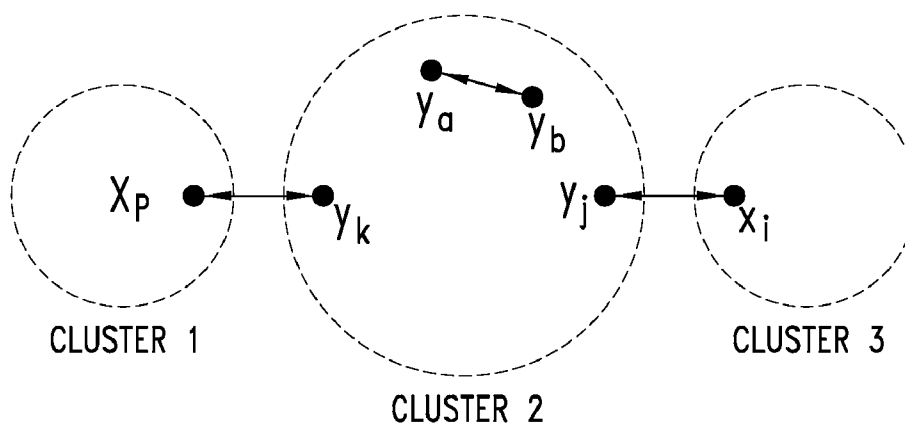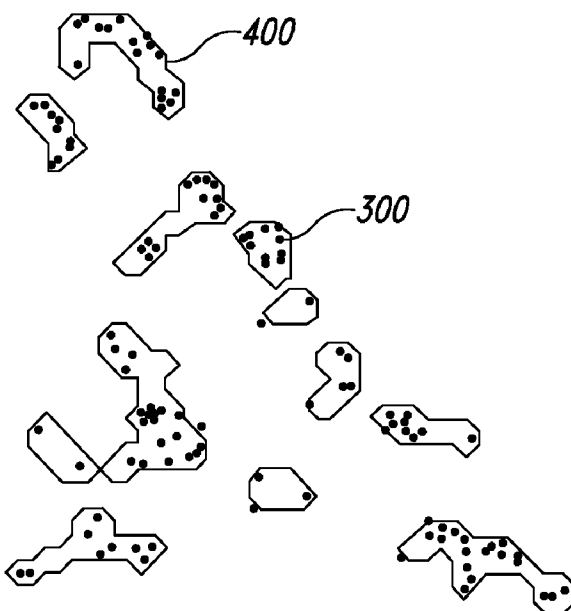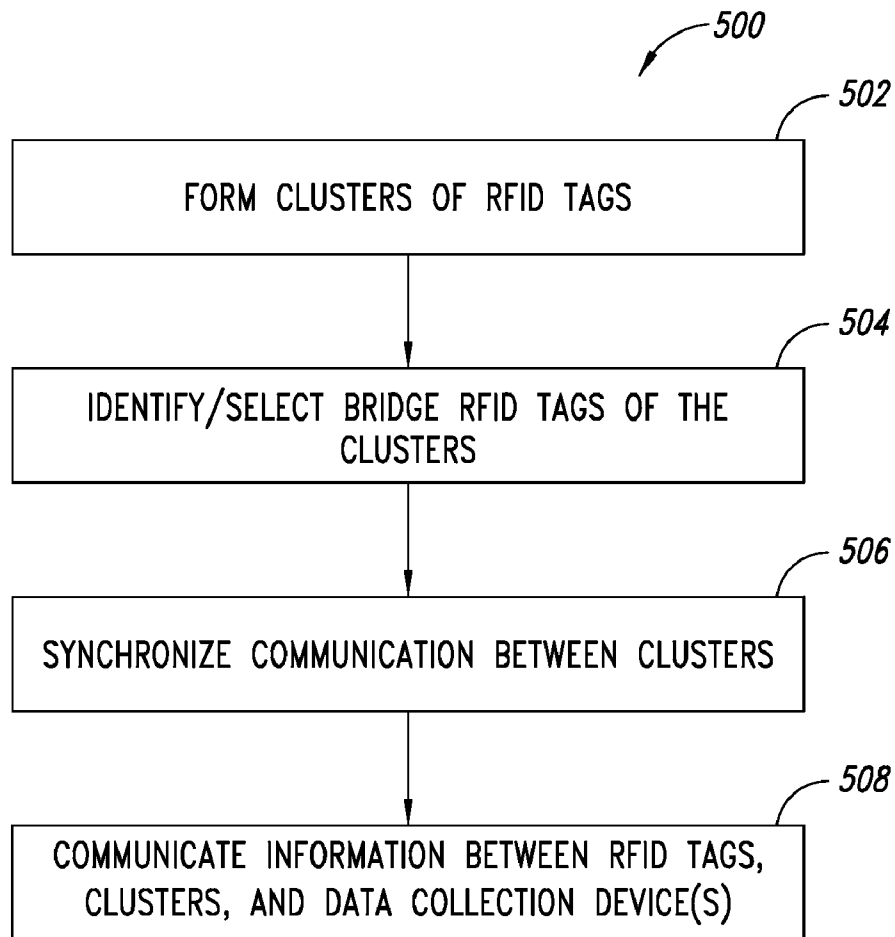
* cited by examiner

FIG. 1



FIG. 2

*300*

*FIG. 3*



*400*

*300*

*FIG. 4*

_500

_502

FORM CLUSTERS OF RFID TAGS

_504

IDENTIFY/SELECT BRIDGE RFID TAGS OF THE CLUSTERS

_506

SYNCHRONIZE COMMUNICATION BETWEEN CLUSTERS

_508

COMMUNICATE INFORMATION BETWEEN RFID TAGS, CLUSTERS, AND DATA COLLECTION DEVICE(S)

*FIG. 5*

*600*

*602* RF CW source

*604*

*606*

RFID tag 1

RFID tag 2

*608*

## FIG. 6

*606* *608*

CW *604* CW CW

SIGNAL

Tag 1 query    Tag 2 response

TIME

## FIG. 7
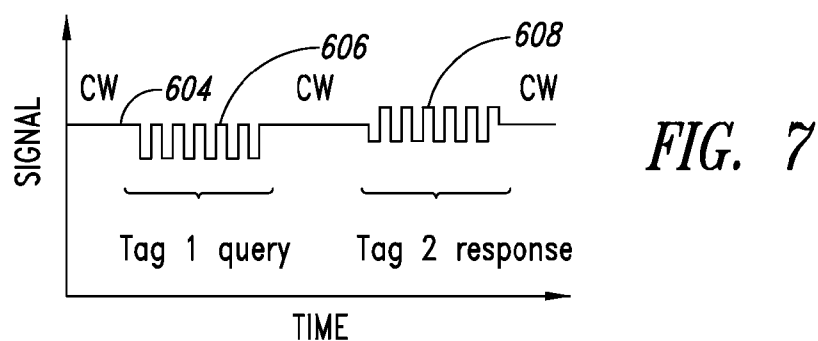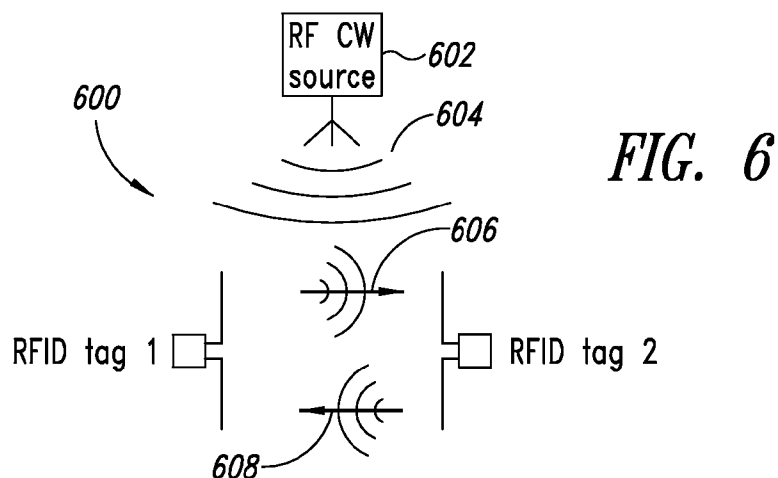
*800*

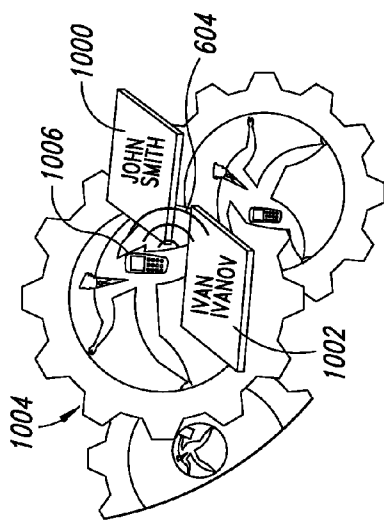| Transmitted RF CW EIRP | 36 dBm |
|---|---|
| Free space path loss from CW source to tag 1 (4 ft distance at 915 MHz) | −33 dB |
| Tag 1 backscattering modulation loss | −6 dB |
| Coupling loss between tag1 and tag2 (tags are in close proximity) | −6 dB |
| Backscattered differential modulated power received by tag 2 | −9 dBm |
| **Minimum power required** | −10 dBm |

## FIG. 8

900

```
                    ┌──────────────────────────────────┐  902
                    │   RECEIVE  RF  CW  AND  POWER  UP  │
                    └──────────────────────────────────┘
                                    │
                                    ▼
         ┌────▶     ┌──────────────────────────────────┐  904
         │          │           START  TIMER            │
         │          └──────────────────────────────────┘
         │                          │
         │                          ▼                906                      908
         │             ◁─────────────────────────▷ Yes   ┌─────────────────────┐
         │             │  RECEIVED  TAG  QUERY?   │─────▶ │  OPERATE  IN  NORMAL │
         │             ◁─────────────────────────▷       │       TAG  MODE      │
         │                          │ No                 └─────────────────────┘
         │                          ▼               910
         │                ┌──────────────────────┐
         │                │     TIME  EXPIRES     │
         │                └──────────────────────┘
         │                          │
         │                          ▼                                        912
         │       ┌────────────────────────────────────────────────┐
         │       │ PERIODICALLY BROADCAST (BACKSCATTER) TAG QUERIES │◀──┐
         │       └────────────────────────────────────────────────┘   │
         │                          │                914                │
         │             ◁─────────────────────────▷ No                  │
         │             │  RECEIVED  TAG  RESPONSE? │─────────────────────┘
         │             ◁─────────────────────────▷
         │                          │ Yes
         │                          ▼                               916
         │       ┌────────────────────────────────────────┐
         │       │          SEND  (BACKSCATTER)  ACK        │
         │       └────────────────────────────────────────┘
         │                          │                               918
         │       ┌────────────────────────────────────────┐
         └───────│    RECEIVE  TAG  ID  AND  STORE  IN  MEMORY │
                 └────────────────────────────────────────┘
```

*FIG. 9*

*FIG. 12*

RF CW BUBBLE

*FIG. 13*

RFID READER

0.1 mm

*FIG. 10*

JOHN SMITH

IVAN IVANOV
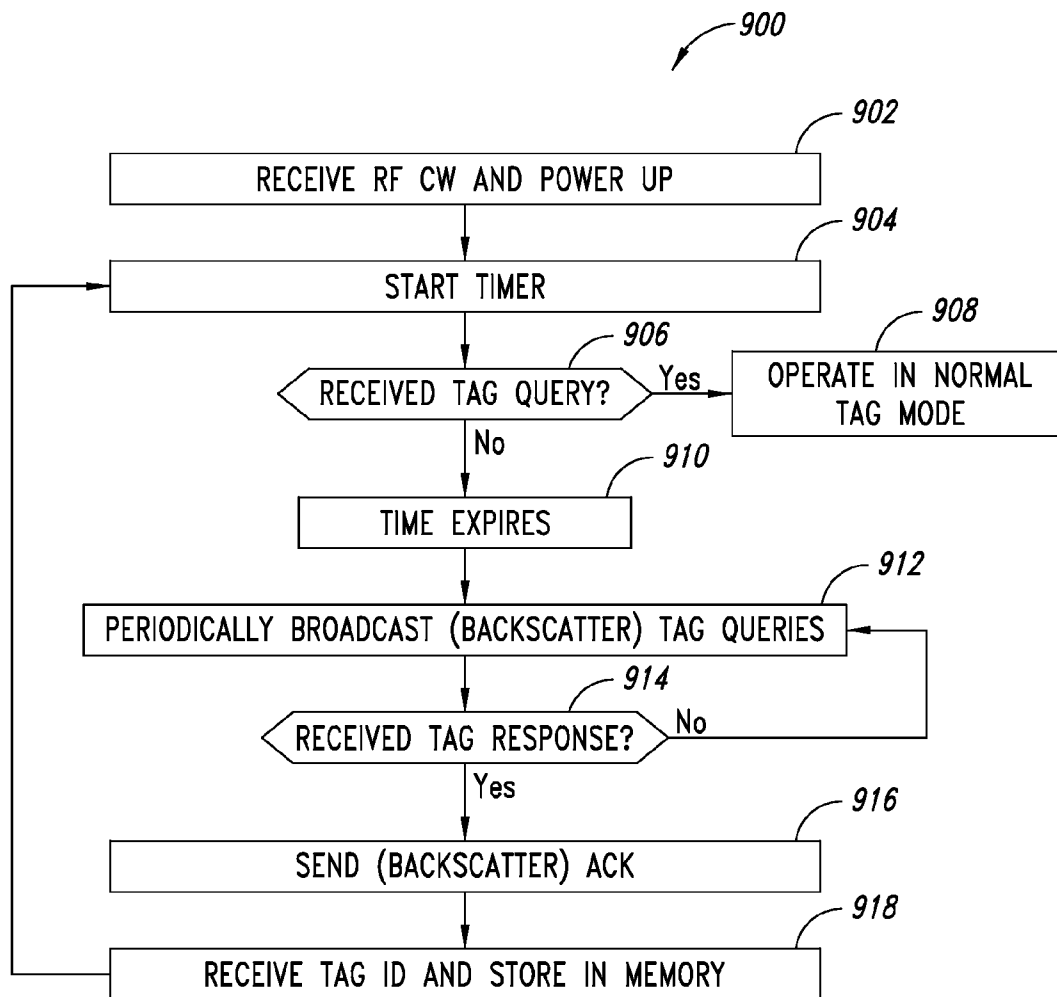
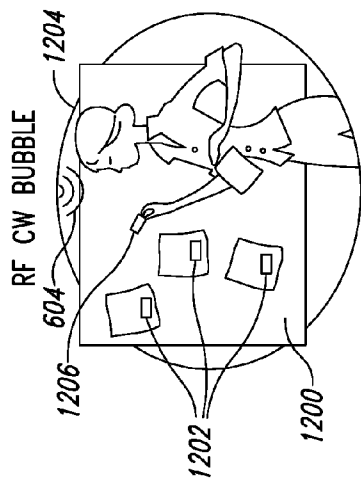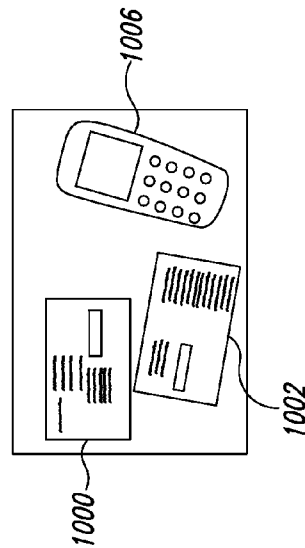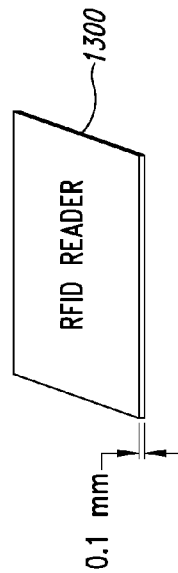*FIG. 11*

# STOCHASTIC COMMUNICATION PROTOCOL METHOD AND SYSTEM FOR RADIO FREQUENCY IDENTIFICATION (RFID) TAGS BASED ON COALITION FORMATION, SUCH AS FOR TAG-TO-TAG COMMUNICATION

## CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a national stage application of Patent Cooperation Treaty (PCT) Application Ser. No. PCT/US2006/036801, filed Sep. 21, 2006, which in turn claims priority to U.S. Provisional Patent Application Ser. No. 60/719,102, entitled "STOCHASTIC COMMUNICATION PROTOCOL AND METHOD OF COALITION FORMATION FOR RF ID TAGS," filed Sep. 21, 2005. These applications are assigned to the same assignee as the present application, and incorporated herein by reference in their entireties.

## TECHNICAL FIELD

This disclosure generally relates to the field of automatic data collection (ADC), for example, data acquisition via radio frequency identification (RFID) tags and readers. More particularly but not exclusively, the present disclosure relates to communication between data carriers such as RFID tags.

## BACKGROUND INFORMATION

The ADC field includes a variety of different types of ADC data carriers and ADC readers operable to read data encoded in such data carriers. For example, data may be encoded in machine-readable symbols, such as barcode symbols, area or matrix code symbols, and/or stack code symbols. Machine-readable symbols readers may employ a scanner and/or imager to capture the data encoded in the optical pattern of such machine-readable symbols. Other types of data carriers and associated readers exist, for example magnetic stripes, optical memory tags, and touch memories.

Other types of ADC carriers include RFID tags that may store data in a wirelessly accessible memory, and may include a discrete power source (i.e., an active RFID tag), or may rely on power derived from an interrogation signal (i.e., a passive RFID tag). RFID readers typically emit a radio frequency (RF) interrogation signal that causes the RFID tag to respond with a return RF signal encoding the data stored in the memory.

Identification of an RFID tag generally depends on RF energy produced by a reader or interrogator arriving at the RFID tag and returning to the reader. Multiple protocols exist for use with RFID tags. These protocols may specify, among other things, particular frequency ranges, frequency channels, modulation schemes, security schemes, and data formats.

Many ADC systems that use RFID tags employ an RFID reader in communication with one or more host computing systems that act as central depositories to store and/or process and/or share data collected by the RFID reader. In many applications, wireless communications is provided between the RFID reader and the host computing system. Wireless communications allow the RFID reader to be mobile, may lower the cost associated with installation of an ADC system, and permit flexibility in reorganizing a facility, for example a warehouse.

RFID tags typically include a semiconductor device having the memory, circuitry, and one or more conductive traces that form an antenna. Typically, RFID tags act as transponders, providing information stored in the memory in response to the RF interrogation signal received at the antenna from the reader or other interrogator. Some RFID tags include security measures, such as passwords and/or encryption. Many RFID tags also permit information to be written or stored in the memory via an RF signal.

RFID tags are generally used to provide information about the specific objects on which the RFID tags are attached. For example, RFID tags may store data that provide the identification and description of products and goods, the identity of an animal or an individual, or other information pertaining to the objects on which the RFID tags are attached.

Some types of RFID tags are capable of communicating with each other, thereby allowing formation of an RFID network. However, direct tag-to-tag communication in such RFID networks is currently possible only between specially designed battery-powered active RFID tags, such as the products available from Axcess Inc. and/or the devices used in the "Smart Dust: Autonomous sensing and communication in a cubic millimeter" project described in http://robotics.eecs.berkeley.edu/~pister/SmartDust/. Such active RFID tags and devices can be unduly complex in design and expensive, especially in situations requiring a large number of tags where the batteries have to be continuously monitored, maintained, and replaced in order to ensure that sufficient power is available to meet operational requirements.

Moreover, traditional client-server applications and methods are not particularly suited for RFID networks that need to be capable of handling very large numbers of interconnected RFID tags in an ad hoc manner. In addition, the RFID tags may dynamically join or leave the RFID network due to a number of reasons, such as exhaustion or lost of power, signal attenuation, physical destruction, etc. The dynamic and generally random nature of the interconnection between and presence of RFID tags, combined with a potentially massive number of distributed RFID tags, as a practical matter preclude the use of traditional applications and methods for communications.

As an additional consideration, the routing table approach used in wired networks and in wireless networks (such as 802.11, ZigBee, Bluetooth, etc. wireless systems) requires a relatively large amount of memory, which is not readily available in RFID tags and therefore cannot be conveniently used in RFID networks. Furthermore, the traditional communication applications and methods are generally unsuitable in RFID networks where the complexity of interconnections between RFID tags requires such communication applications/methods to address scalability, pervasiveness, spatial distribution, power awareness, and/or other issues.

## BRIEF SUMMARY

One aspect provides a method that includes forming coalitions of clusters of distributed data carriers. For each of said clusters, the method identifies a bridge data carrier that is capable to link with a bridge data carrier of another of said clusters, and enables communication between data carriers of the clusters. At least some of said data carriers include batteryless passive data carriers.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments are described with reference to the following drawings, wherein

like reference numerals refer to like parts throughout the various views unless otherwise specified. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not drawn to scale, and some of these elements are arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn, are not intended to convey any information regarding the actual shape of the particular elements, and have been solely selected for ease of recognition in the drawings.

FIG. 1 is a schematic diagram showing a formation of clusters of distributed RFID tags according to an embodiment.

FIG. 2 is a schematic diagram showing use of bridge tags to implement communication between clusters according to an embodiment.

FIGS. 3-4 are schematic diagrams showing formation of clusters based on distances between RFID tags according to an embodiment.

FIG. 5 is a flowchart of an embodiment of a method for stochastic communication between RFID tags, such as the RFID tags shown in FIGS. 1-3.

FIG. 6 is a block diagram of an embodiment of a system to provide direct tag-to-tag communication between passive RFID tags of clusters.

FIG. 7 is a schematic diagram illustratively showing modulation of a carrier wave (CW) by an embodiment of the system of FIG. 6 for direct tag-to-tag communication between passive RFID tags of clusters.

FIG. 8 is a table showing example power levels associated with direct tag-to-tag communication between RFID tags of clusters.

FIG. 9 is a flowchart of an embodiment of a method that can be implemented in the system of FIG. 6 for direct tag-to-tag communication between passive RFID tags of clusters.

FIGS. 10-12 are schematic diagrams that show example implementations for direct tag-to-tag communication between passive RFID tags of clusters.

FIG. 13 is a schematic diagram that shows an embodiment of an apparatus with RFID reading capability that is usable for direct tag-to-tag communication between passive RFID tags of clusters.

## DETAILED DESCRIPTION

In the following description, numerous specific details are given to provide a thorough understanding of embodiments. One skilled in the relevant art will recognize, however, that the embodiments can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations associated with RFID tags and RFID readers, computer and/or telecommunications networks, and/or computing systems are not shown or described in detail to avoid obscuring aspects of the embodiments.

Unless the context requires otherwise, throughout the specification and claims which follow, the word "comprise" and variations thereof, such as, "comprises" and "comprising" are to be construed in an open, inclusive sense, that is as "including, but not limited to."

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment.

Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

The headings provided herein are for convenience only and do not interpret the scope or meaning of the embodiments.

As an overview, data carriers (such as RFID tags) are formed into clusters of data carriers. Each cluster has at least one bridge data carrier that can communicate with a bridge data carrier of another cluster, thereby allowing data carriers in each cluster to communicate directly or indirectly with each other using a stochastic communication protocol method.

The clusters can be formed dynamically based on various criteria, such as the distance associated with candidate data carriers, such as a distance between a candidate data carrier and a centrally located data carrier in a cluster. Moreover, the size, shape, number of data carriers, etc. for each cluster can vary dynamically from one cluster to another.

Another embodiment relates to a synchronization of formed coalitions of clusters of distributed data carriers to sustain a collection of data of interest in a desired manner.

Embodiments further provide techniques for direct tag-to-tag communication between data carriers (such as passive RFID tags) in each cluster and/or between clusters. Such embodiments allow such data carriers to backscatter and modulate a carrier wave from a source, thereby using the backscattered and modulated carrier wave to convey data to each other.

The stochastic communication protocol method of one embodiment includes the following elements:

(a) forming stochastic coalitions of clusters from irregularly or otherwise randomly distributed RFID tags;

(b) identifying bridge tags for each cluster;

(c) synchronizing cluster formations; and

(d) enabling distribution of information between RFID tags and a data collection device.

FIG. 1 shows a non-limiting example of the first element (a) of such a method, namely formation of stochastic coalitions of clusters from distributed RFID tags. In particular, the diagram of FIG. 1 shows formation of a plurality of clusters of data carriers, such as a set of RFID tags $Y=\{y_1, y_2, y_3, \ldots, y_N\}$, according to one embodiment. For the sake of simplicity of explanation hereinafter and unless otherwise specified, the data carriers will be described in the context of RFID tags. In other embodiments, it is appreciated that the data carriers can comprise acoustical tags, other types of non-RFID tags, and/or a combination of RFID tags and non-RFID tags.

Each of the clusters in FIG. 1 are denoted by $C^i$, where $1 \leq i < k$ and $k < N$. Each cluster C includes an RFID tag $x_i$, where $1 \leq i \leq k$. In one embodiment, the RFID tag $x_i$ in each cluster $C^i$ comprises an RFID tag that is located substantially in the center of each cluster. Thus, the cluster $C^1$ has the central RFID tag $x_1$; the cluster $C^2$ has the central RFID tag $x_2$; the cluster $C^3$ has the central RFID tag $x_3$; and so forth up to the cluster $C^k$ having the central RFID tag $x_k$. In another embodiments, the RFID tag $x_i$ need not necessarily be the centrally located RFID tag in each cluster $C^i$.

The various RFID tags Y in FIG. 1 include deployed RFID tags that are affixed to objects. Such objects can include an item, a packaging or label for the item, a container of multiple packaged or unpackaged items, or other type of objects that are capable of having the RFID tags Y attached thereon. Examples of the item can include drugs, toys, food, animals, merchandise, human beings, machinery parts, or other types of animate or inanimate items that can be identified or otherwise represented by the RFID tags Y. In the context of human beings, for example, the item can include an identification

card, driver's license, airline boarding pass, article of clothing, luggage, and so forth. Moreover, the RFID tags Y can be affixed to stationary objects, such as objects placed on an inventory shelf. The RFID tags Y may also be affixed to objects in motion, such as on identification cards carried by persons. The RFID tags may also be affixed to a combination of stationary and in-motion objects, and may further dynamically change in total number N (as well as the total number of RFID tags in each cluster $C^k$) as RFID tags are added or removed from a cluster, run out of power or are otherwise disabled, lost or detached from their respective object, and so forth.

Accordingly in one embodiment, the RFID tags Y in FIG. 1 are randomly distributed in a non-confined area. In another embodiment, the distribution may be less random, for example if the objects having the RFID tags Y affixed thereon are organized uniformly on a shelf or other situation where the distribution of the RFID tags Y is more or less uniform.

The clusters C of FIG. 1 are formed based on the principles of coalition formation in one embodiment. The coalitions (or other form of grouping) of the RFID tags Y of one embodiment define RFID tags as agents that may or may not communicate with each other. Coalitions can be formed between linked agents—thus, a coalition can encompass two (or more) clusters that are able to communicate with each other; a coalition can encompass two (or more) RFID tags in different clusters that can communicate with each other; and/or a coalition can encompass two (or more) RFID tags in a same cluster that can communicate with each other. In a first type of communication in an embodiment, RFID tags directly communicate with each other in order to be in the same coalition. In a second type of communication in an embodiment, RFID tags may communicate indirectly with each other through the use of other agents. In one embodiment, the structure of the random coalitions controls the functionality of the coalitions, and the efficiency of communication protocols between RFID tags in effect determines the functionality of the coalitions. Further details of such various embodiments are described in further detail later below. The publication Kirman et al., "Stochastic Communication and Coalition Formation," Econometrica, volume 54, No. 1 (January 1986), pages 129-138 also provides additional details of coalitions that can be implemented by some embodiments and is incorporated by reference herein in its entirety.

In mathematical terms for one embodiment, the set of RFID tags $Y=\{y_1, y_2, y_3, \ldots, y_N\}$ is divided into k subsets (clusters C), with the RFID tags $x_i$ being centrally located tags in each cluster, where $1 \leq i \leq k$ and $k < N$. Under these conditions, the following criterion will have a maximum value:

$$\sum_{x_i} \sum_{y_j \in S(x_i)} \mu(x_i, y_j)$$

where $S(x_i)$ is a set of RFID tags that belong to a cluster $C^i$ with the RFID tag $x_i$ as a central RFID tag, and $\mu(x_i, y_j)$ is some measure of communication quality between tags $x_i$ and $y_j$ (with i and j<N). In one embodiment, the measure of communication quality is based on emitted power, as will be explained with regards to FIG. 2. In other embodiments, the measure of communication quality can be based on additional or alternative factors.

FIG. 2 shows a non-limiting example of the second element (b) of an embodiment of the stochastic communication protocol method, namely identification of bridge RFID tags for each cluster $C^i$. In an embodiment, the identification of bridge RFID tags (e.g., the RFID tags $x_p$, $y_k$, $y_i$, and $x_i$ in FIG. 2) includes identification of RFID tags in every cluster C such that all clusters have links with each other directly or indirectly through intermediate clusters via use of bridge RFID tags.

In the example of FIG. 2, the cluster 1 includes a particular RFID tag $x_p$. The RFID tag $x_p$ may be the central RFID tag or may be some other tag located off-center in the cluster 1. The cluster 2 includes particular RFID tags $y_k$ and $y_j$. The RFID tags $y_k$ or $y_j$ may be the central RFID tag or may be some other tag located off-center in the cluster 2. The cluster 2 also includes other RFID tags $y_a$ and $y_b$ that can communicate with each other, as depicted by the double-headed arrow between the RFID tags $y_a$ and $y_b$. The cluster 3 includes the RFID tag $x_i$. The RFID tag $x_i$ may be the central RFID tag or may be some other tag located off-center in the cluster 3.

In the example of FIG. 2, the RFID tags $x_p$ and $y_k$ are the bridge RFID tags that can communicate with each other (as depicted by the double headed arrow between the RFID tags $x_p$ and $y_k$), thereby allowing other RFID tags in the respective clusters 1 and 2 to indirectly communicating with each other through the bridge RFID tags $x_p$ and $y_k$. Thus, a coalition is formed between the bridge RFID tags $x_p$ and $y_k$, between the clusters 1 and 2, and/or between any RFID tag in cluster 1 with any RFID tag in cluster 1 (via communication with the bridge RFID tags $x_p$ and $y_k$).

Similarly, the RFID tags $y_j$ and $x_i$ are the bridge RFID tags that can communicate with each other (as depicted by the double headed arrow between the RFID tags $y_j$ and $x_i$), thereby allowing other RFID tags in the respective clusters 2 and 3 to indirectly communicating with each other through the bridge RFID tags $y_j$ and $x_i$. Thus, a coalition is formed between the bridge RFID tags $y_j$ and $x_i$, between the clusters 2 and 3, and/or between any RFID tag in cluster 2 with any RFID tag in cluster 3 (via communication with the bridge RFID tags $y_j$ and $x_i$).

In an embodiment, a "bridge zone" in each cluster (e.g., in clusters 1 and 2) is defined by the region where the emitting power of the particular RFID tag $x_p$ of the cluster 1 that is sensed by the particular RFID tag $y_k$ of the cluster 2 exceeds a cumulative power that is sensed by the particular RFID tag $y_k$ from all of the RFID tags in the cluster 1 by some specified threshold value. In some embodiments, the specified threshold value exceeded by the cumulative power is uniform among the various clusters. In another embodiment, the specified threshold value can be different among the various clusters. For instance, the specified threshold value between clusters 1 and 2 can be different than the specified threshold value between clusters 2 and 3.

In an embodiment, a single cluster may have different bridge RFID tags that can be used to bridge with respective different other clusters. Further in an embodiment, a single cluster may have more than one bridge RFID tag to bridge with some other single cluster, and/or may bridge with more than one bridge RFID tag of that other single clusters. Still further in an embodiment, various RFID tags may be designated as backup bridge RFID tags, if a primary bridge RFID tag becomes disabled, is removed from the cluster, or otherwise becomes incapable of operating as a bridge RFID tag.

In yet further embodiments, the identification of bridge RFID tags may change dynamically, as the shape or size of a cluster changes and/or as additional RFID tags are added/removed from the cluster. It is therefore evident from the above that individual RFID tags are capable of communicating with other RFID tags, whether in the same cluster or in

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some other cluster, by "hopping" from one RFID tag to another communicatively compatible RFID tag in the same cluster and between clusters.

FIGS. 3-4 show an embodiment of a technique for forming clusters based on distances between RFID tags. It is appreciated that formation of clusters based on distances is only one possible technique that can be used. Other embodiments can form clusters based on other alternative or additional factors, such as RFID type, power output, return signal frequency, and so forth.

In FIG. 3, a plurality of RFID tags 300 are distributed over a region. The region over which the RFID tags 300 are distributed can range from a few square inches (or smaller) to perhaps on the order of several square miles. As depicted symbolically in FIG. 3, some RFID tags 300 are located in closer proximity relative to each other as compared to other ones of the RFID tags 300. The particular concentration/density, pattern, location, or other distribution factor of the RFID tags 300 can be completely random, semi-random, specifically arranged, and/or combination thereof.

As depicted in FIG. 4, clusters 400 of the RFID tags 300 are formed based on distances between RFID tags 300. Specifically in one embodiment, RFID tags 300 that are closer in distance to each other are formed into the same cluster. Various techniques can be used to determine whether the distance between RFID tags is sufficient or insufficient to justify inclusion of any given RFID tag into a cluster. In one technique, RFID tags are included in the same cluster if the distance between any two of the RFID tags is less than some specified distance. Any RFID tag that exceeds the specified distance to the closest RFID tag of the cluster is rejected for inclusion in the cluster, and is considered instead for inclusion in some other cluster.

In another technique, a particular RFID tag is designated as a central RFID tag $x_i$ for a cluster. Then, the other RFID tags of the cluster are identified and selected based on some specified distance from the central tag $x_i$. For example, RFID tags are included in the same cluster if the distance between such RFID tags and the central RFID tag $x_i$ is less than some specified distance. Any RFID tag that exceeds the specified distance to the central RFID tag $x_i$ of the cluster is rejected for inclusion in the cluster, and is considered instead for inclusion in some other cluster.

Again and as previously explained above, the size, shape, number of RFID tags, etc. of each cluster can dynamically vary from one cluster to another based on various factors. Moreover, it is possible to have a cluster having only a single RFID tag. Such single RFID tag can thus act as its own bridge RFID tag to other clusters.

In an embodiment, each of the clusters previously described above includes at least one active RFID tag and one or more passive RFID tags. In another embodiment, all RFID tags in one or more of the clusters may be passive RFID tags, and one or more devices (such as an automatic data collection device, including RFID readers) can provide the RF field(s) to power such passive RFID tags to perform the various functionalities described herein. In yet other embodiments, some clusters may have one active RFID tag and one or more passive RFID tags, while other clusters may have only passive RFID tags, while still other clusters may have only active RFID tags—all of these clusters have the capability to communicate with each other (directly or indirectly) using the methods described herein.

FIG. 5 is a flowchart of an embodiment of a method 500 to implement the various elements of the stochastic communication protocol described above. It is appreciated that the various operations in the flowchart of FIG. 5 need not neces-

sarily occur in the exact order shown. Moreover, certain operations can be added, removed, modified, or combined.

In some embodiments, certain operations of the method 500 can be implemented in software or other machine-readable instruction stored on a machine-readable medium and executable by a processor. For example, some of the operations in the method 500 can be performed by a data collection device (such as an RFID reader) in one embodiment, using one or more processors and a storage medium of the data collection device.

At a block 502, all of the RFID tags are assigned to a particular cluster that has some RFID tag $x_i$ as a central tag, thereby forming clusters of RFID tags. As described above with reference to FIGS. 3-4, the assignment of tags to a particular cluster can be based on distances between RFID tags. Also as explained above, other criteria can be used to assign RFID tags to specific clusters.

At a block 504, bridge RFID tags are identified and selected. As described above for one embodiment, the identification and selection of bridge RFID tags can be performed based on bridge zones where the emitting power of the particular RFID tag of a first cluster that is sensed by a particular RFID tag of a second cluster exceeds some cumulative power of all RFID tags of the first cluster that is sensed by the particular RFID tag of the second cluster.

At a block 506 for one embodiment, communication between and/or within clusters is synchronized, such as time synchronization of transmission and/or reception. The synchronization can be localized (e.g., synchronization between neighboring RFID tags in a same and/or adjacent clusters) and/or at least partially global (e.g., synchronization between all RFID tags in a same cluster, synchronization between a plurality of clusters, synchronization of all RFID tags of all clusters). In one embodiment, such synchronization can be performed using methods known to persons skilled in the art. Other embodiments can use the synchronization techniques disclosed in U.S. Provisional Patent Application Ser. No. 60/610,759, entitled "SYNCHRONIZATION OF ADAPTIVE SELF-CONFIGURING WIRELESS NETWORK OF TRANSPONDERS," filed Dec. 1, 2004, assigned to the same assignee as the present application, and incorporated herein by reference in its entirety.

One example of such synchronization techniques includes global-based time synchronization in which all RFID tags set time to send/receive data based on a single (e.g., a common) time clock located inside and/or outside of the RFID network. In one embodiment that can implement this synchronization technique, an RFID tag is able to receive data even though such an RFID tag may not necessarily have the capability to communicate the acknowledgement of a successful reception of the data, due to factors such as power constraints. This synchronization technique is used for global synchronization in one embodiment, but can also be adapted for local synchronization.

Another example is time-stamped packet communication in which the packets or other data format received by a recipient RFID tag includes a time of transmission from a sender RFID tag. Embodiments can implement this synchronization technique in a global and/or localized basis.

Yet another example is tag-to-tag synchronization in which the time for transmission/reception is set by an outside system and propagated to the RFID tags. Such propagation can be done by having the RFID tags within and/between clusters send the time from one RFID tag to another.

A variation to the tag-to-tag synchronization involves an RFID tag (performing managerial duties for its cluster) that sets the time and propagates the time to collaborating neigh-

bor RFID tags. In one embodiment, the central RFID tag $x_i$ can be used as the managerial tag, although other RFID tags in the cluster may also be used as primary and/or backup managerial RFID tags. The cluster's time may be synchronized locally or globally when a tag-to-tag synchronization technique is used.

Still another example of synchronization involves multi-hop time synchronization in which time error is compensated/corrected during propagation of data. In still a further example, RFID tags are capable of identifying a synchronization mode and can start corroboration with neighboring RFID tags in accordance with a proposed synchronization mode. Furthermore, in the case of multiple clusters of RFID tags, RFID tags may reconcile multiple global times to continue an appropriate communication mode.

In other embodiments, the synchronization at the block **506** need not be performed and/or need be performed only on a limited basis. Thus for such embodiments, there need not necessarily be synchronization between RFID tags in a same cluster, between RFID tags of different clusters, between clusters, and/or between other communicating elements of the RFID networks.

At a block **508** in the method **500** of FIG. **5**, information is communicated between RFID tags, clusters, and/or data collection device(s) or other device(s). Such communication can be direct or indirect communication within or between clusters using the bridge RFID tags as described above. Specific embodiments of direct tag-to-tag communication that can be implemented in the clusters previously described above will be explained next.

More particularly and beginning with FIG. **6**, shown generally at **600** is an embodiment of a system **600** for direct tag-to-tag communication between two passive RFID tags **1** and **2**. The RFID tags **1** and **2** can comprise two bridge RFID tags of two different clusters described above, or two RFID tags within the same cluster, for instance. Either or both RFID tags **1** and **2** can in turn perform direct tag-to-tag communication with yet other RFID tags in the same cluster and/or with a bridge RFID tag, thereby allowing indirect communication with yet other RFID tags in another cluster.

For embodiments of the system **100** having RFID tags, the system **600** includes an RF carrier wave (RF CW) source **602** that generates a carrier wave **604**. The RF CW source **602** can be embodied as an automatic data collection device (such as an RFID reader), a cellular telephone or other portable communication device, another RFID tag, and or any other device(s) or combination thereof that are capable of generating an unmodulated carrier wave **604** that can be used for direct tag-to-tag communication, as well as a power source for the RFID tags **1** and **2**. In another embodiment, the carrier wave **604** is output from the RF CW source **602** in a modulated form, and is then further modulated by the RFID tags **1** and **2** during tag-to-tag communication.

In one embodiment, the RF CW source **602** can be switched ON or OFF mechanically (such as by an operator) or electronically (such as in response to a wireless signal). The RF CW source **602** can be powered from a portable battery, thereby providing a portable solution, or from a stationary source of power, for example a 120 V AC voltage supply, thereby providing an industrial solution. Moreover, the RF CW source **602** can be integrated as an operating mode option in a cellular telephone or other device, and produced inexpensively since no frequency stability or digital signal processing capability is used in one embodiment.

An example embodiment of the RF CW source **602** can use a 5 V battery with up to 1 watt of output RF power, using Micro Device's RF2131 power amplifier integrated circuit

(IC) with resonant feedback. Additionally in an embodiment, several RC CW sources **602** can be arranged in an array or other pattern so as to cover a large area where clusters of RFID tags are present.

In operation the carrier wave **604** is backscattered, and the RFID tags **1** and **2** can communicate with each other by modulating the backscattered carrier wave **604**. Thus, the RFID tag **1** can send an interrogation signal **606** to the RFID tag **2**, and the RFID tag **2** can reply to the interrogation signal **606** with a reply signal **608**, and/or vice versa. The interrogation signal **606** and the return signal **608** are thus the modulated backscattered carrier wave **604**. The interrogation signal **606** and the return signal **608** can be demodulated by the RFID tags **2** and **1**, respectively, to obtain the data encoded therein.

The method of communication of FIG. **6** can be analogized by an example of two persons in a dark room. When a light in the room if OFF, the two persons cannot see each other in the dark. When the light in the room is ON, the two persons can see each other and remember each other's appearance because of photons of light that reflect from them and make them visible to each other. In an analogous way, the two passive RFID tags **1** and **2** cannot communicate with each other in the absence of the carrier wave **604**, but in the presence of the carrier wave **604**, the two RFID tags **1** and **2** can communicate with each other by modulating the backscattered carrier wave **604**.

Example waveforms at terminals of the RFID tags **1** and **2** during tag-to-tag communication are illustrated in FIG. **7**. It is appreciated that such illustrated waveforms are not intended to be precisely depicted in shape, frequency, amplitude, timing, etc. in FIG. **7**, but are rather intended to be drawn for the purpose of clarity of explanation.

The carrier wave **604** is depicted in FIG. **7** as a signal of constant amplitude during periods of time when the carrier wave **604** is not being modulated by the RFID tags **1** and **2**. During a period of time when the RFID tag **1** generates and sends the interrogation signal **606** to the RFID tag **2**, FIG. **7** depicts the modulation of the carrier wave **604** as a square wave pulse train. Similarly, during a period of time when the RFID tag **2** generates and sends the return signal **608** to the RFID tag **1**, FIG. **7** depicts the modulation of the carrier wave **604** as another square wave pulse train.

FIG. **8** is a table **800** showing example power budget values for the tag-to-tag communication described above. It is appreciated that the various power values shown in the table **800** are merely for the purpose of illustration, and that other embodiments may involve different power values.

The RF CW source **602** is assumed to output the carrier wave **604** with a power value of +36 dBm. The free space path loss from the RF CW source **602** to the RFID tag **1** (assuming a distance of 4 feet between the RF CW source **602** and the RFID tag **1**, with a 915 MHz frequency for the carrier wave **604**) is −33 dB, thereby leaving +3 dBm of power available. There is then a backscattering modulation loss of −6 dB associated with the RFID tag **1**, as well as a coupling loss of −6 dB between the RFID tags **1** and **2** in close proximity. The resulting backscattering differential modulated power received by the RFID tag **2** is thus −9 dBm. If the minimum power required for tag-to-tag communication is −10 dBm, then the resultant −9 dBm power is sufficient to meet operational requirements.

In one embodiment, the carrier wave **604** from the RF CW source **602** comprises an interrogation signal that both powers and interrogates the RFID tag **1** and/or the RFID tag **2**. Such an interrogation signal can then be modulated by the RFID tag **1** and/or the RFID tag **2** in the manner described above,

thereby providing tag-to-tag communication capabilities in existing passive RFID networks/systems.

In another embodiment, one of the RFID tags (such as the RFID tag **2**) can comprise a passive RFID tag with capabilities to receive interrogation signals and to send return signals, and another one of the RFID tags (such as the RFID tag **1**) can comprise a passive RFID tag having additional capability to independently broadcast or otherwise issue tag queries (i.e., interrogation signals), alternatively or additionally to using the carrier wave **604** for such tag queries. Such an embodiment of the RFID tag **1** obtains power from the carrier wave **604** (or from some other source) and then waits for the RF CW source **602** to transmit an interrogation signal, which may be in the form of a modulation of the carrier wave **604** and/or the issuance of another signal. If the RFID tag **1** does not receive any interrogation signals from the RF CW source **1** within a period of time, then the RFID tag **1** starts to periodically broadcast (such as by backscattering) interrogation signals itself to the RFID tag **2** and/or to other RFID tags. Such interrogation signals can comprise a modulated or unmodulated carrier wave similar to the carrier wave **604**, in one embodiment.

In another embodiment, both the RFID tags **1** and **2** can have the capability to issue interrogation signals. In still further embodiments, RFID tags of the various clusters can comprise a mix of RFID tags with or without this additional capability to issue interrogation signals.

FIG. **9** is a flowchart of a method **900** for direct tag-to-tag communication in which one of the RFID tags (such as the RFID tag **1** for purposes of illustration) has capability to issue interrogation signals. It is appreciated that the various operations in the flowchart of FIG. **9** need not necessarily occur in the exact order shown. Moreover, certain operations can be added, removed, modified, or combined.

In some embodiments, certain operations of the method **900** can be implemented in software or other machine-readable instruction stored on a machine-readable medium and executable by a processor. For example, some of the operations in the method **900** can be performed by one or more controllers or other processor(s) and a storage medium in an RFID tag.

At a block **902**, the RFID tags **1** and **2** receive the carrier wave **604** from the RF CW source **602** and power up. A timer in the RFID tag **1** is started at a block **904**. If the RFID tag **1** receives an interrogation signal at a block **906** from the RF CW source **602** and/or from some other querying device, then the RFID tag **908** operates in a normal tag mode at a block **908**, such as by generating and sending an appropriate return signal to the querying device(s).

However, if the timer expires at a block **910** and the RFID tag **1** has not received an interrogation signal at the block **906**, then the RFID tag **1** sends one or more interrogation signals or other types of queries at a block **912** to an RFID tag (such as the RFID tag **2**). In one embodiment, the queries at the block **912** are broadcast periodically, such as by backscattering. In other embodiments, the queries need not necessarily be sent in a periodical manner, and can be sent in a somewhat random manner, for example.

If the RFID tag **1** does not receive any return signals or other response(s) to the queries at a block **914**, then the RFID tag **1** continues to issue queries at the block **912**. However, if the RFID tag **1** receives one or more responses at the block **914**, then the RFID tag **1** generates and sends back (such as by backscattering) a corresponding one or more acknowledgements at a block **916**.

At a block **918**, the RFID tag **1** receives an RFID tag identifier (such as the identifier for the RFID tag **2**) from the

RFID tag **2** during the direct tag-to-tag communication and stores this received RFID tag identifier in memory. The method **900** then repeats at the block **904** in which the timer of the RFID tag **1** is restarted as the RFID tag **1** monitors for additional tag queries.

FIGS. **10-12** show various example implementations for direct tag-to-tag communication where RFID tags (or other types of data carriers, such as acoustical tags) are arranged in clusters. It is appreciated that such implementations are not intended to be exhaustive of all the possible implementations for direct tag-to-tag communication.

The implementation illustrated in FIG. **10** involves direct exchange of information, without the use of a dedicated automatic data collection device such as an RFID reader, between documents embedded with passive RFID tags containing information pertaining to the documents. Examples of such documents as illustrated in FIG. **10** are business cards **1000** and **1002**, such that the passive RFID tags embedded therein contain business card information.

The exchange of business card information can be performed if there is an area **1004** where the carrier wave **604** is present to energize the RFID tags embedded in the business cards **1000** and **1002**. The area **1004** can be an area in a conference center, for example, is covered by the carrier wave **604** generated by the RF CW source **602**. Alternatively or additionally, the carrier wave **604** can be generated from a device such as a cellular telephone **1006** or other device capable to generate the carrier wave **604**. In one embodiment, the cellular telephone **1006** can be a conventional cellular telephone that does not require modification in order to generate the carrier wave **604**.

FIG. **11** further illustrates the implementation shown in FIG. **10**. Two persons need to quickly and conveniently exchange business card information. One of these persons pushes a button on the cellular telephone **1006** to create a "bubble" or other area proximate to the business cards **1000** and **1002** to be covered by the carrier wave **604**. By pressing the button or otherwise appropriately actuating the cellular telephone **1006**, the cellular telephone **10056** can operate in an RF CW mode. The "bubble" can be present for a few seconds or any other suitable length of time sufficient to allow the RFID tags of the business cards **1000** and **1002** to conduct tag-to-tag communication.

The two persons can "rub" their business cards **1000** and **1002** together, or otherwise place the business cards **1000** and **100** in close proximity to each other, in order to conduct the tag-to-tag communication to exchange and store business card information of the other person. The two persons can then go their separate ways, and can later retrieve the stored business card information (such as at home, at the office, or at some other location). The business card information stored in the embedded RFID tag of the business cards **1000** and **1002** can be retrieved at such other locations using an automatic data collection device (such as an RFID reader), a personal computer of laptop with RFID-reading capability, or other device capable to read RFID tags.

In the example of FIG. **12**, a person approaches a bulletin board **1200** having advertisements **1202** present thereon. The advertisements **1202** have passive RFID tags that contain information pertaining to each advertisement **1202**. An area **1204** ("bubble") encompassing the bulletin board **1200** is covered by the carrier wave **604** from the RF CW source **602**, which could be a stationary device placed proximate to the bulletin board **1200**, a cellular telephone of the person, or some other device.

The person can read the information from selected advertisements **1202** using a personal passive RFID tag **1206**, such

as by "swiping" the RFID tag **1206** over the selected advertisement(s) **1202**. The information read from the RFID tags of the advertisements **1202** can then be stored by the RFID tag **1206** of the person for later review or other use.

In an embodiment, the RFID tag **1206** of the user can be embedded in a business card or other object, in a handheld device portable communication device (such as a cellular telephone, pager, PDA, Blackberry, Palm Pilot, etc.), or some other compact and portable apparatus that can be conveniently carried by the person and usable to "swipe" over one or more RFID tags or other target data carriers.

An embodiment of such an apparatus having the RFID tag for reading other RFID tags is shown at **1300** in FIG. **13**. The apparatus **1300** can be a "paper thin" batteryless RFID reader, with an example thickness of 0.1 mm. The apparatus **1300** of one embodiment comprises a passive RFID tag having capability to issue interrogation or other query signals in accordance with the embodiment of the method **900** shown in FIG. **9**. The apparatus **1300** of one embodiment can be provided with sufficient memory capacity to store information from a large number of RFID tags that are read. The stored information can later be retrieved from the apparatus **1300** using an RFID reader or other suitable automatic data collection device.

Advantages of the apparatus **1300** are compact size, lightweight, batteryless, and relatively inexpensive (for example, less than a few dollars each). Moreover, such an apparatus **1300** can operate anywhere in a vicinity of RFID tags that are covered by the carrier wave **604** generated by the RF CW source **602**.

Accordingly from the various embodiments of the RFID clusters and tag-to-tag communication techniques between RFID tags of such clusters described above, it is clear that such embodiments can be used for real time applications and/or to meet other application requirements. Additional advantages of such embodiments can further include, but not be limited to, indifference to RFID network topology changes (e.g., adaptive and self-configuring clusters), energy efficient functionality, extended range for automatic data collection device or other device for collecting data (since tags can communicate directly or indirectly with each other using bridge tags), thereby extending the range for reading tags), self-organizing capability, and so forth.

All of the above U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, are incorporated herein by reference, in their entirety.

The above description of illustrated embodiments, including what is described in the Abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments and examples are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention and can be made without deviating from the spirit and scope of the invention.

For example, embodiments have been described above in which the RFID tags are attached to objects, and provide data pertaining to the objects. In other embodiments, the RFID tags may be provided with sensor elements, such that the RFID tags can detect and collect data regarding temperature, humidity, air pressure, lighting levels, presence of certain chemical substances, presence and strength of electromagnetic or other types of signals, or other environmental condition that can be sensed and stored by the RFID tags. Such

detected and collected data can then be provided to one or more RFID readers and/or to other RFID tags using the techniques described above.

Furthermore, various embodiments have been described above in the context of the data carrier being in the form of an RFID tag. It is appreciated that other embodiments can be provided for use with other types of data carriers, such as acoustical tags. In such other embodiments, the carrier wave (CW) can be in the form of an acoustical wave. Further in such embodiments, the acoustical tags can be formed into clusters and can communicate with each other in a manner analogous to the techniques described above. Further, various systems can include clusters formed entirely of acoustical tags; clusters formed from a mix of acoustical tags, RFID tags, and/or other types of tags; and/or clusters formed from various other combinations of tag types that can communicate with similarly or differently formed clusters.

In the embodiments described above, various signals (such as the carrier wave **604**) have been described as being an RF signal. It is understood that the RF signal(s) can be included in at least the radio band and microwave band of frequencies.

These and other modifications can be made to the embodiments in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

What is claimed is:

1. A method, comprising:
forming clusters of distributed data carriers;
for each of said clusters, identifying a bridge data carrier that is operable to communicate with a bridge data carrier of another of said clusters by defining a bridge zone as a region where a power output level from said at least one of said data carriers in a first cluster, which is sensed by another one of said data carriers in a second cluster, exceeds a cumulative power that is sensed by said another one of said data carriers from all of the data carriers in the first cluster by a threshold value;
enabling communication between data carriers of the different clusters via the identified bridge data carrier, at least some of said data carriers including batteryless passive data carriers, wherein each data carrier in the cluster is operable to communicate with the respective bridge data carrier; and
forming coalitions of clusters of distributed data carriers based on the enabled communication between the data carriers of the different clusters, each coalition of clusters including at least two of the clusters of distributed data carriers.

2. The method of claim **1** wherein at least some of said batteryless passive data carriers include passive RFID tags.

3. The method of claim **1** wherein at least some of said batteryless passive data carriers includes acoustical tags.

4. The method of claim **1** wherein forming coalitions of clusters of distributed data carriers includes forming coalitions of randomly distributed data carriers, said coalitions including a coalition between clusters, a coalition between data carriers of respective different clusters, and a coalition between data carriers in a same cluster.

5. The method of claim **1** wherein forming coalitions of distributed data carriers includes identifying candidate data carriers to place in a cluster based on whether a distance between said candidate data carriers is within a value.

**6**. The method of claim **5** wherein one of said identified candidate data carriers is a substantially central data carrier, wherein said distance is a distance between the central data carrier and another of said candidate data carriers.

**7**. The method of claim **1** wherein enabling the communication between the data carriers includes enabling indirect communication between non-bridge data carriers of different clusters using their respective bridge data carriers, enabling direct or indirect communication between data carriers in a same cluster, or enabling communication between data carriers of different clusters using their respective bridge data carriers and at least one intermediate cluster and the bridge data carriers of the intermediate cluster.

**8**. The method of claim **1** wherein enabling communications between data carriers of the clusters includes:

providing a carrier wave that can be backscattered;

modulating the backscattered carrier wave with a first of said data carriers to generate an interrogation signal; and

modulating the backscattered carrier wave with a second of said data carriers to generate a return signal in response to the interrogation signal.

**9**. The method of claim **8** wherein the first of said data carrier initiates modulation of the backscattered carrier wave by:

receiving power from the carrier wave; and

monitoring for a query signal associated with the carrier wave for a period of time;

wherein when the query signal is not detected after expiration of the period of time, generating and sending the interrogation signal to query the second of said data carriers; and

when the query signal is detected prior to expiration of the period of time, responding to the query signal.

**10**. The method of claim **8** wherein providing the carrier wave includes providing the carrier wave from a portable data collection or communication device.

**11**. The method of claim **8** wherein providing the carrier wave includes providing the carrier wave from another data carrier that is adapted to generate the carrier wave.

**12**. The method of claim **11** wherein said another data carrier is embedded in a business card, an advertisement, or a document.

**13**. The method of claim **1** wherein forming coalitions of clusters of distributed data carriers includes forming a cluster having only one data carrier.

**14**. The method of claim **1** wherein forming coalitions of clusters of distributed data carriers includes forming coalitions having a mix of battery powered active data carriers and said passive data carriers.

**15**. The method of claim **1** wherein enabling communication between data carriers of the clusters includes enabling communication using a stochastic communication protocol that includes synchronization of communication.

**16**. The method of claim **15** wherein the synchronization of communication includes localized time synchronization between at least two data carriers.

**17**. The method of claim **15** wherein the synchronization of communication includes global time synchronization between data carriers of a plurality of said clusters.

**18**. The method of claim **15** wherein the synchronization of communication includes global-based time synchronization in which communication time between data carriers is set in accordance with a common time clock.

**19**. The method of claim **15** wherein the synchronization of communication includes time-stamped data communication in which data received by a recipient data carrier from a sender data carrier includes a time of transmission of the data.

**20**. The method of claim **15** wherein the synchronization of communication includes data carrier-to-data carrier synchronization includes:

setting a time, and propagating the set time from one data carrier to another; or

using one of the data carriers designated as a managerial data carrier to set the time, and propagating the set time from the managerial data carrier to neighbor data carriers.

**21**. The method of claim **15** wherein the synchronization of communication includes multiple-hop time synchronization in which time error is compensated for during communication.

**22**. The method of claim **15** wherein the synchronization of communication includes:

providing a plurality of different synchronization modes; and

allowing at least some of the data carriers to identify one of said synchronization modes and to corroborate with neighbor data carriers in accordance with the identified synchronization mode.

**23**. A system, comprising:

At least a first and second clusters of distributed data carriers, wherein for each of said first and second clusters, a bridge data carrier is identified that is operable to link with a bridge data carrier of another of said first and second clusters; and

means for enabling communication between the data carriers of the first and second clusters, some of said data carriers including batteryless passive carriers,

wherein said bridge data carrier is identified according to a region where a power output level from a first data carrier in the first cluster, which is sensed by a second data carrier in the second cluster, exceeds a cumulative power that is sensed by said second data carrier from all of the data carriers in the first cluster by a threshold value.

**24**. The system of claim **23** wherein said means for enabling communication between data carriers of the clusters includes:

source means for providing a carrier wave that can be backscattered; and

means for modulating the backscattered carrier wave to generate interrogation and return signals therefrom, said interrogation and return signals being communicated between at least two of said data carriers.

**25**. The system of claim **24** wherein one of said data carriers includes means for independently generating the interrogation signal after an expiration of time, alternatively or additionally to generating the interrogation signal using the carrier wave.

**26**. The system of claim **23** wherein said clusters includes a candidate data carrier placed in a particular cluster based on a distance between said candidate data carrier and a substantially central data carrier in the particular cluster.

**27**. A system, comprising:

a plurality of clusters of distributed data carriers, some of said data carriers including batteryless passive data carriers; and

for each of said clusters, a bridge data carrier that is operable to link with a bridge data carrier of another of said clusters to enable communication between data carriers of the clusters, said communication including modulation of a backscattered carrier wave to convey interrogation and return signals between data carriers of the clusters,

wherein the modulation of the backscattered carrier wave is initiated by:

receiving power from the carrier wave; and

monitoring for a query signal associated with the carrier wave for a period of time,

wherein when the query signal is not detected after expiration of the period of time, generating and sending the interrogation signal to query the second of said data carriers; and

when the query signal is detected prior to expiration of the period of time, responding to the query signal, and

wherein the bridge data carriers are determined based at least in part on a region where a power output level from a first data carrier in a first cluster, which is sensed by a second data carrier in a second cluster, exceeds a cumulative power that is sensed by said second data carrier from all of the data carriers in the first cluster by a threshold value.

28. The system of claim 27, further comprising a carrier wave source to generate the carrier wave.

29. The system of claim 28 wherein said carrier wave source includes portable wireless communication device, one of said data carriers embedded in an object, or an automatic data collection device.

30. The system of claim 28 wherein said one of said data carriers embedded in the object is adapted to generate the carrier wave to interrogate at least another one of said data carriers in response to expiration of a specified time period.

31. The system of claim 27 wherein said clusters include dynamically formed clusters of randomly distributed data carriers that can communicate with each other using a stochastic communication protocol.

32. The system of claim 27 wherein each of the clusters includes a substantially central data carrier, wherein a candidate data carrier is adapted to be considered to include in a particular cluster based on a distance between the candidate data carrier and the central data carrier of the particular cluster.

33. An article of manufacture, comprising:

a storage medium usable with a plurality of distributed data carriers arranged into clusters, the storage medium having instructions stored thereon that are executable by a processor associated with a first passive data carrier to provide communication between passive ones of said data carriers, by:

receiving a carrier wave;

starting a timer;

monitoring for an interrogation signal;

when the interrogation signal is not received before expiration of the timer, generating the interrogation signal by modulating the carrier wave;

sending the interrogation signal to at least a second data carrier; and

continuing to send the interrogation signal to the second data carrier until a response signal is received from the second data carrier,

wherein the storage medium further includes instructions stored thereon that are executable by said processor to provide communication between passive ones of said data carriers, by identifying a bridge data carrier associated with the cluster of the second data carrier based at least in part on a cumulative output power level of at least some of the data carriers in the cluster of the second data carrier, wherein the bridge data carrier is identified based at least in part on a region where a power output level from the bridge data carrier sensed by one of data carriers in the cluster of the first data carrier exceeds the cumulative power output level of all the data carriers in the cluster of the second data carrier, that is sensed by the one of the data carriers in the cluster of the first data carrier, by a threshold value.

34. The article of manufacture of claim 33 wherein the second data carrier is in a different cluster than the first passive data carrier, said instructions to send the interrogation signal including instructions that are executable by said processor to provide communication between passive ones of said data carriers, by:

sending the interrogation signal to a bridge data carrier associated with the cluster of the second data carrier.

35. The article of manufacture of claim 33 wherein the first and second data carriers are both passive RFID data carriers of a same or different cluster.

36. The article of manufacture of claim 33 wherein said storage medium is at least partially integrated with a sensor.

37. The article of manufacture of claim 36 wherein said sensor is adapted to detect and collect data regarding at least one of a plurality of parameters related to temperature, humidity, air pressure, lighting levels, presence of certain chemical substances, presence and strength of electromagnetic or other types of signals, or other environmental condition.

38. The article of manufacture of claim 33 wherein the first passive data carrier is adapted to generate a broadcast signal.

39. The article of manufacture of claim 33 wherein the response signal of the second data carrier is a broadcast signal.

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