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(54) **COOPERATIVE SECURITY IN WIRELESS SENSOR NETWORKS**

(71) Applicant: **Intel Corporation**, Santa Clara, CA (US)

(72) Inventors: **Robert Lawson Vaughn**, Portland, OR (US); **Osvaldo Diaz**, Portland, OR (US); **Siu Kit Wai**, Lam Tin (HK); **Igor Tatourian**, Fountain Hills, AZ (US)

(73) Assignee: **Intel Corporation**, Santa Clara, CA (US)

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H04W 24/04 (2009.01)
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(52) **U.S. Cl.**
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See application file for complete search history.

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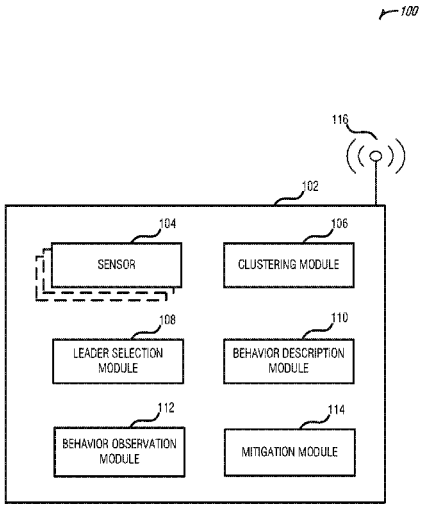
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Primary Examiner — Fayyaz Alam
(74) *Attorney, Agent, or Firm* — Schwegman Lundberg & Woessner, P.A.

(57) **ABSTRACT**

Systems, apparatuses, and methods for cooperative security in wireless sensor networks are described herein. A wireless node may organize itself into a cluster with other wireless nodes. The wireless node may cooperate with other wireless nodes in the cluster to select a leader node. The wireless node may describe its expected behaviors. The wireless node may detect a compromised wireless node within the cluster. The wireless node may prevent the compromised wireless node from compromising another wireless node.

25 Claims, 5 Drawing Sheets



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H04W 4/38	(2018.01)
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H04W 12/00	(2009.01)
H04W 84/20	(2009.01)
H04W 24/02	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 12/00*** (2013.01); ***H04W 12/12*** (2013.01); ***H04W 24/04*** (2013.01); *H04W 24/02* (2013.01); *H04W 84/20* (2013.01)

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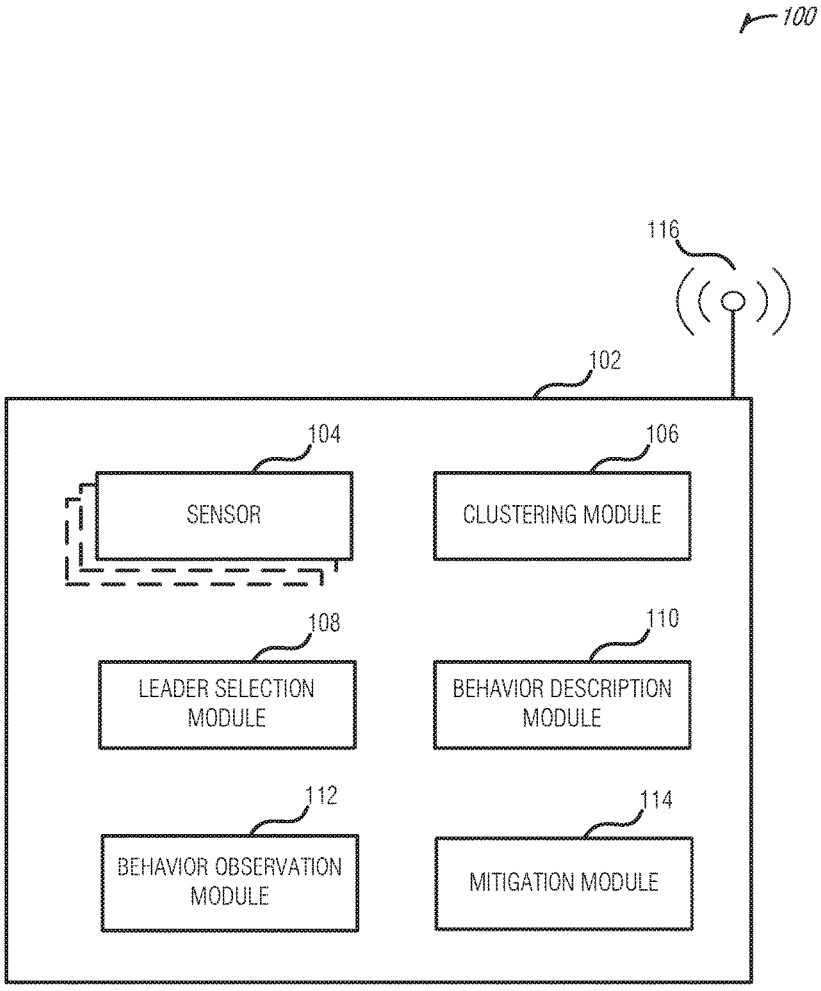


FIG. 1

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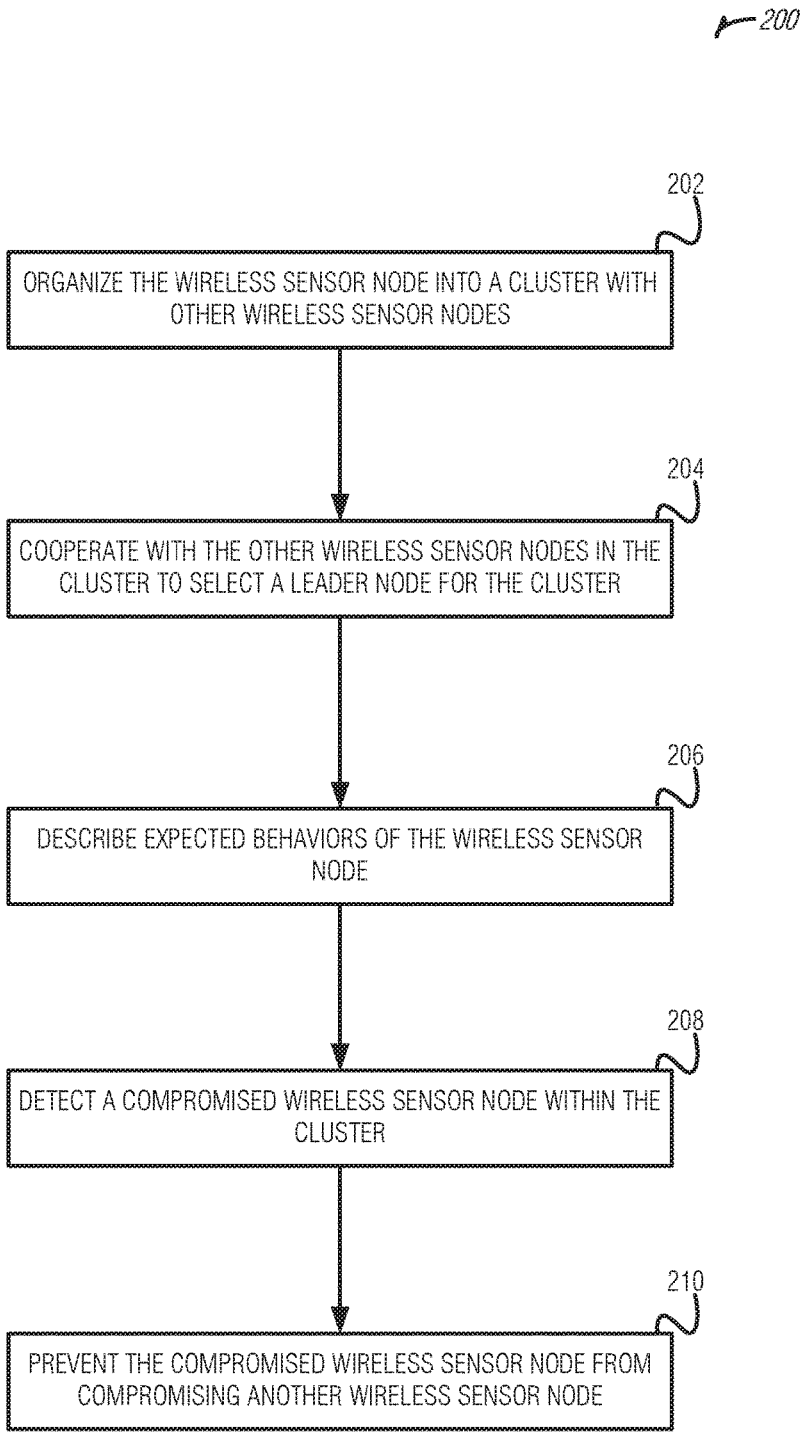

200
202
ORGANIZE THE WIRELESS SENSOR NODE INTO A CLUSTER WITH OTHER WIRELESS SENSOR NODES
204
COOPERATE WITH THE OTHER WIRELESS SENSOR NODES IN THE CLUSTER TO SELECT A LEADER NODE FOR THE CLUSTER
206
DESCRIBE EXPECTED BEHAVIORS OF THE WIRELESS SENSOR NODE
208
DETECT A COMPROMISED WIRELESS SENSOR NODE WITHIN THE CLUSTER
210
PREVENT THE COMPROMISED WIRELESS SENSOR NODE FROM COMPROMISING ANOTHER WIRELESS SENSOR NODE

FIG. 2

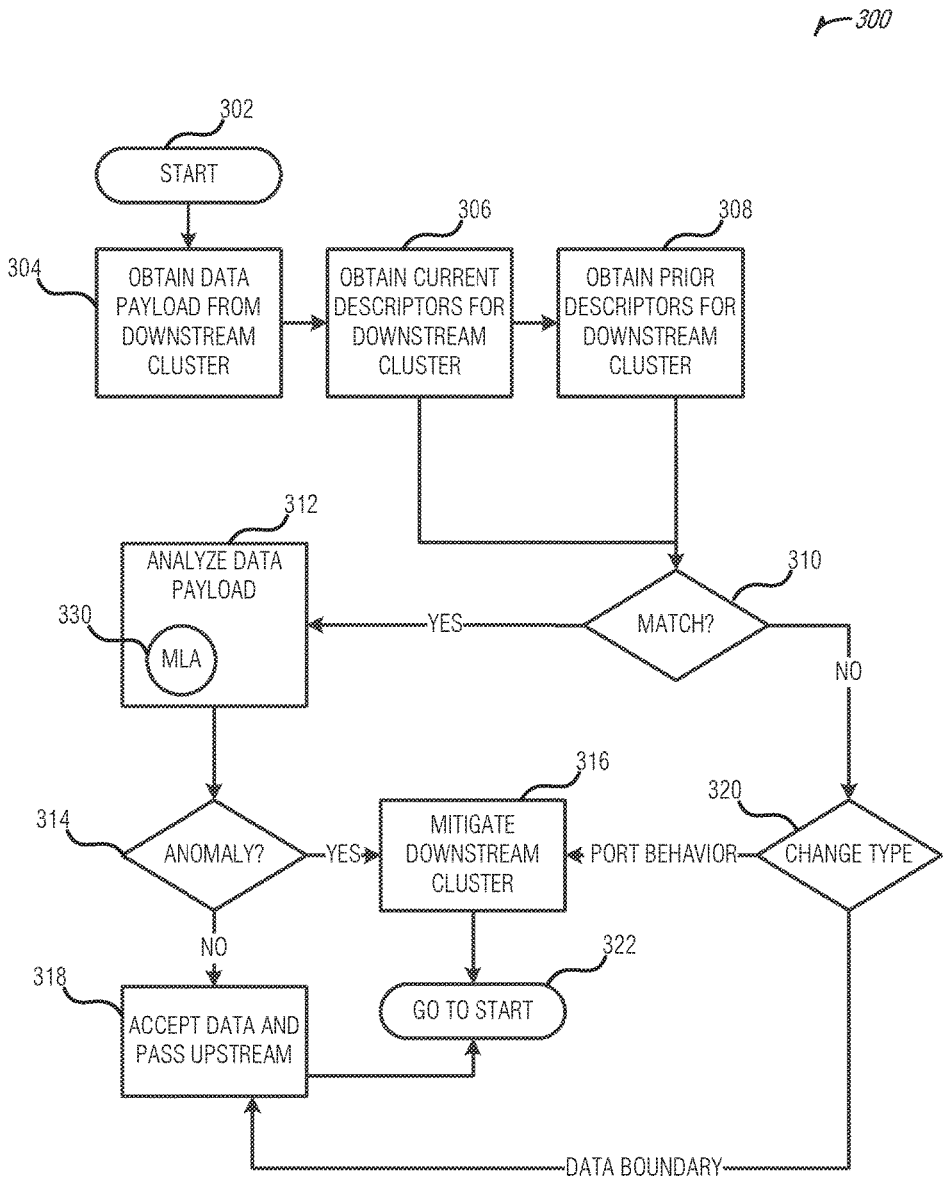

300
302
START
304
OBTAIN DATA PAYLOAD FROM DOWNSTREAM CLUSTER
306
OBTAIN CURRENT DESCRIPTORS FOR DOWNSTREAM CLUSTER
308
OBTAIN PRIOR DESCRIPTORS FOR DOWNSTREAM CLUSTER
310
MATCH?
YES
NO
312
ANALYZE DATA PAYLOAD
330
MLA
314
ANOMALY?
YES
316
MITIGATE DOWNSTREAM CLUSTER
320
PORT BEHAVIOR
CHANGE TYPE
NO
318
ACCEPT DATA AND PASS UPSTREAM
322
GO TO START
DATA BOUNDARY

FIG. 3

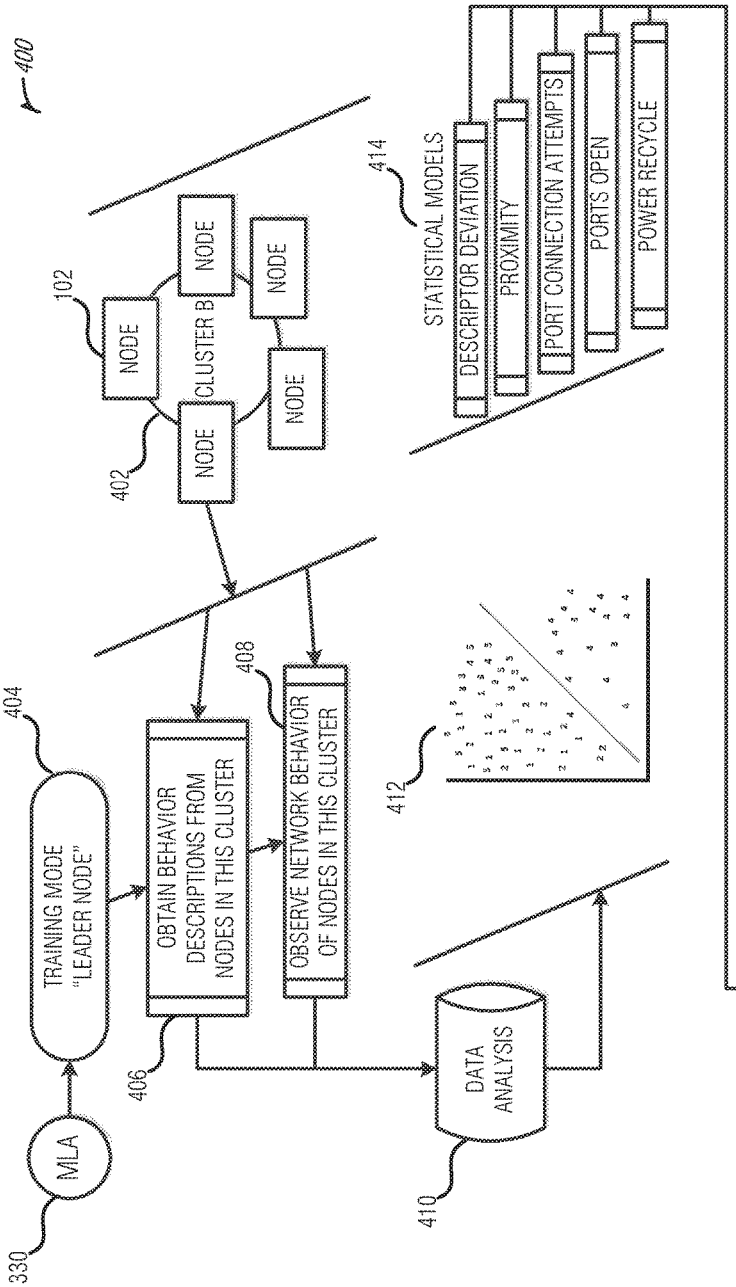

400
102
NODE
NODE
NODE
NODE
NODE
NODE
CLUSTER B
402
STATISTICAL MODELS
414
DESCRIPTOR DEVIATION
PROXIMITY
PORT CONNECTION ATTEMPTS
PORTS OPEN
POWER RECYCLE
404
TRAINING MODE "LEADER NODE"
OBTAIN BEHAVIOR DESCRIPTIONS FROM NODES IN THIS CLUSTER
406
408
OBSERVE NETWORK BEHAVIOR OF NODES IN THIS CLUSTER
412
DATA ANALYSIS
410
MLA
330
STORE RANGE BOUNDARIES
416
MLA
330

FIG. 4

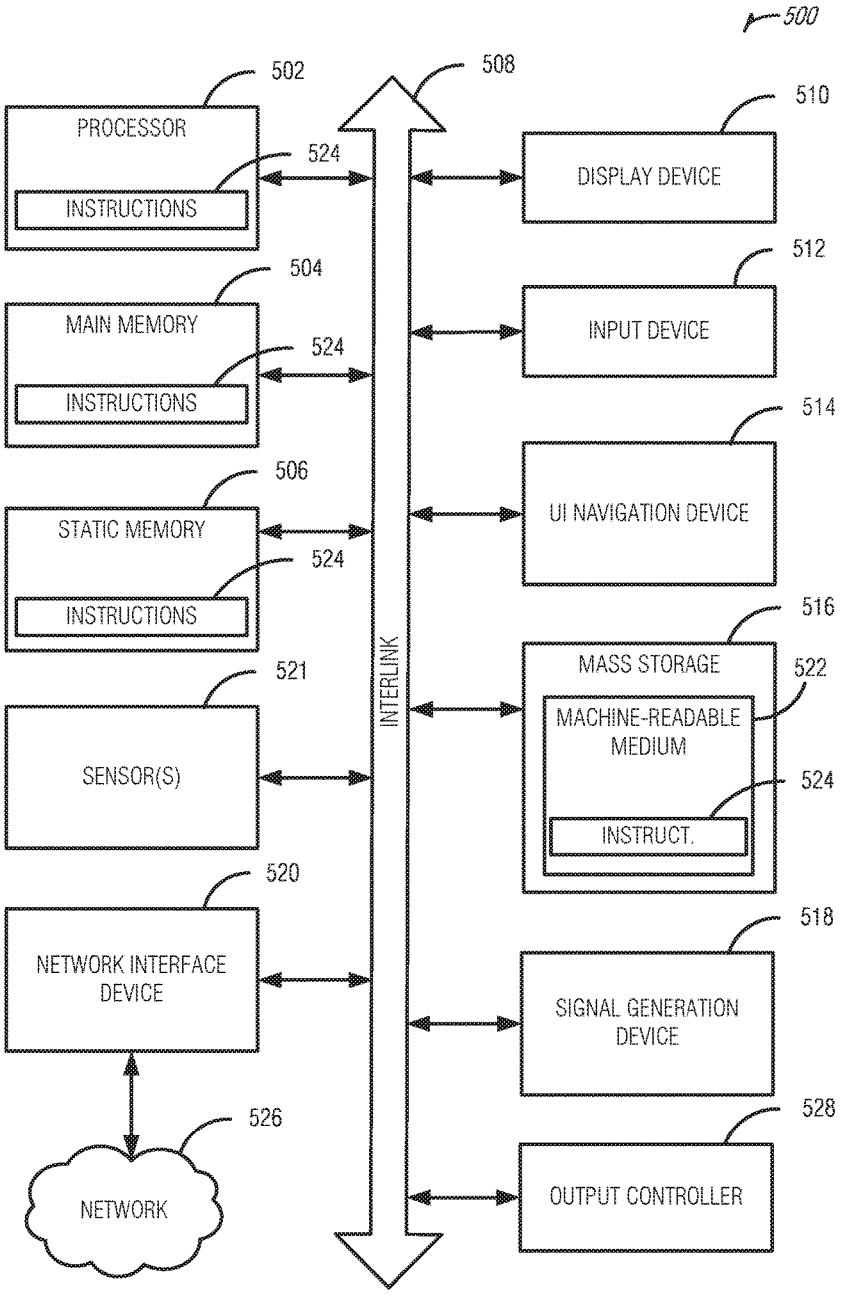

500
502
PROCESSOR
524
INSTRUCTIONS
504
MAIN MEMORY
524
INSTRUCTIONS
506
STATIC MEMORY
524
INSTRUCTIONS
521
SENSOR(S)
520
NETWORK INTERFACE DEVICE
526
NETWORK
508
INTERLINK
510
DISPLAY DEVICE
512
INPUT DEVICE
514
UI NAVIGATION DEVICE
516
MASS STORAGE
522
MACHINE-READABLE MEDIUM
524
INSTRUCT.
518
SIGNAL GENERATION DEVICE
528
OUTPUT CONTROLLER

FIG. 5

COOPERATIVE SECURITY IN WIRELESS SENSOR NETWORKS

PRIORITY APPLICATION

This application is a continuation of U.S. application Ser. No. 14/577,764, filed Dec. 19, 2014, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure generally relates to wireless sensor networks and, in an embodiment, to cooperative security in wireless sensor networks.

BACKGROUND

A wireless sensor network (WSN) is a network of wireless nodes equipped with sensors to monitor physical or environmental conditions, such as temperature, air pressure, flow rate, sound pressure, etc. A wireless node transmits the data collected by its sensor to a destination. In an example, the wireless node may pass the data to another wireless node that is "closer" (either physically or logically) to the destination than the originating wireless node; this process continues until the data is delivered to the destination.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments are illustrated by way of example and not limitation in the figures of the accompanying drawings.

FIG. **1** is a block diagram of a wireless sensor node arranged to participate in cooperative security within a wireless sensor network, according to an embodiment.

FIG. **2** is a flowchart illustrating a process performed by a wireless sensor node within a wireless sensor network employing cooperative security, according to an embodiment.

FIG. **3** is a flowchart illustrating a process performed by an upstream cluster in analyzing communications from downstream clusters, according to an embodiment.

FIG. **4** is an illustration of a machine learning process for observing behavior of wireless sensor nodes within a cluster to develop a model of expected behavior for the wireless sensor nodes within the cluster, according to an embodiment.

FIG. **5** is a block diagram illustrating an example of a machine, upon which one or more example embodiments may be implemented.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the various aspects of the presently disclosed subject matter. However, it will be to those skilled in the art that the presently disclosed subject matter may be practiced without these specific details. In other instances, well-known methods, procedures, and components have not been described in detail so as not to obscure the presently disclosed subject matter.

The use of wireless sensor networks is increasing rapidly in a variety of applications including in industrial settings, such as manufacturing, supply chain, and energy production/distribution. Furthermore, the quantity of wireless sensor nodes (e.g., devices) in deployments of wireless sensor networks continues to increase. It is common for some

wireless sensor networks to have hundreds or even thousands of wireless sensor nodes. As the quantity of wireless sensor nodes increases, identifying nodes that have been compromised (e.g., by virus, malware, etc.) becomes increasingly complex. Accurately identifying compromised nodes while managing false positives in a timely manner may become a significant challenge.

As the quantity of wireless sensor nodes increases, wireless sensor nodes of wireless sensor networks may police themselves in an intelligent manner to (1) reduce the computing resources expended by backend/centralized facilities, (2) leverage commonality of function and proximity of devices to reduce network traffic, and (3) minimize false positive alerts. These objectives may be met by a cooperative security model that allows distributed wireless sensor nodes to pattern the expected behavior of nodes within the network and to react appropriately to deviations from the expected behavior.

In an embodiment, wireless sensor nodes (including nodes at the edges of the wireless sensor network) work in a cooperative manner to identify a compromised node and mitigate its chance of compromising other wireless sensor nodes in the network, whether upstream or downstream from the compromised node. The wireless sensor nodes cooperatively organize themselves into clusters, and each cluster chooses a leader node. The leader node uses machine learning techniques to create a model of expected behaviors of the nodes within its cluster, and then uses the model of expected behaviors to decide whether the observed behavior of a node within the cluster indicates that the node is compromised. The leader node compares observed behavior to the expected behavior, and based on these observations, determines that a wireless sensor node within its cluster is compromised. Upon determining that a wireless sensor node within its cluster is compromised, the leader mitigates the ability of the compromised node to compromise other nodes within the cluster.

FIG. **1** is a block diagram of a wireless sensor node **102** arranged (e.g., configured, designed, manufactured, etc.) to participate in cooperative security within a wireless sensor network according to an embodiment. In an embodiment, wireless sensor node **102** includes a set of sensors **104**. In an embodiment, sensor set **104** includes one sensor. In an embodiment, sensor **104** is arranged to monitor one or more physical and/or environmental conditions, such as temperature, air pressure, flow rate, sound pressure, pH level, radioactivity, etc. In an embodiment, sensor set **104** includes multiple sensors, each of which is arranged to monitor one or more physical and/or environmental conditions, some which may differ from one another. For example, one sensor s arranged to monitor temperature, while another sensor is arranged to monitor flow rate.

In an embodiment, wireless sensor node **102** includes at least one antenna **116**, which the wireless sensor node **102** uses for data transmissions (both inbound and outbound). In an embodiment, wireless sensor node **102** acquires data collected by the sensor **104**, and transmits this data in either real-time, substantially near real-time, or in batch mode. In an embodiment, wireless sensor node **102** is arranged to analyze or transform some of the data collected by sensor **104** prior to transmitting the data. In an embodiment, wireless sensor node **102** is arranged to add to or remove from the data collected by sensor **104** prior to transmitting the data. In an embodiment, wireless sensor node **102** is arranged to selectively refuse to transmit some or all of the data collected by sensor **104**.

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In an embodiment, wireless sensor node **102** includes clustering module **106**. In an embodiment, clustering module **106** of wireless sensor node **102** is arranged to cooperate with other wireless sensor nodes **102** in the wireless network to organize wireless sensor node **102** into a cluster with the other wireless sensor nodes **102**. In an embodiment, a cluster of wireless sensor nodes **102** is arranged to form based on proximity (either physical proximity, network proximity, and/or logical proximity), on the type(s) of sensor(s) **104** included in wireless sensor nodes **102**, on a level of redundancy to be created within the cluster, on hardware and/or software capabilities of the wireless sensor nodes **102**, etc., or some combination thereof.

In an embodiment, wireless sensor node **102** includes leader selection module **108**. In an embodiment, leader selection module **108** of wireless sensor node **102** is arranged to cooperate with the leader selection modules **108** of the other wireless sensor nodes **102** in the cluster to select one of the wireless sensor nodes **102** in the cluster to be the leader node for the cluster.

In an embodiment, upon a wireless sensor node **102** having been selected as leader node by the wireless sensor nodes **102** within its cluster, the leader node is arranged to proxy all communications to be transmitted out of or to be received by a wireless sensor node **102** within the cluster. The leader node continues to proxy all communications into and out of the cluster until another leader node is chosen and/or until the leader node determines itself to have been compromised.

In an embodiment, wireless sensor node **102** includes behavior description module **110**. In an embodiment, behavior description module **110** is arranged to describe the expected behavior of wireless sensor node **102**. In an embodiment, behavior description module **110** is arranged to describe the expected behavior of wireless sensor node **102** by describing one or more data parameters to be transmitted by or to be received by the wireless sensor node **102**. A data parameter may be a data sample collected by a sensor **104**, a data sample collected by a sensor **104** and modified by wireless sensor node **102** (e.g., converting between metric values and U.S./Imperial values), data generated by wireless sensor node **102** (e.g., node ID, up-time, GPS coordinates, etc.), or data wireless sensor node **102** expects to receive (e.g., cluster ID, operational instructions from the leader node of the cluster, etc.).

In an embodiment, a data parameter includes the name of the parameter, a data type for the parameter (e.g., date, time, integer, datetime, long, double, etc.), and a valid range for the parameter. In an embodiment, the range is indicated by a bottom value that indicates the lowest value of the data type allowed for the parameter (e.g., −100) and a top value that indicates the highest value of the data type allowed for parameter (e.g., 3000). In an embodiment, the behavior description module **110** is arranged to describe the expected behaviors of the wireless sensor node **102** using Extensible Markup Language (XML), JavaScript Object Notation (JSON), YAML (YAML Ain't Markup Language), or some other data representation. In an embodiment, a description of expected behavior of wireless sensor node **102** includes a digital signature from a trusted third party. In an embodiment, the digital signature is used to verify that the description of expected behavior for wireless sensor node **102** has not been modified or corrupted. In an embodiment, the behavior description module **110** of wireless sensor node **102** is arranged to be configurable after the wireless sensor node **102** has been deployed. In an embodiment, the behavior description module **110** of wireless sensor node **102** is arranged to be configurable while the wireless sensor node **102** is operating. In an embodiment, the behavior description module **110** of wireless sensor node **102** is arranged to be configurable with descriptions of updated or new data parameters to describe a new expected behavior for the wireless sensor node **102**.

In an embodiment, behavior description module **110** is arranged to broadcast the description of its expected behaviors to other wireless sensor nodes **102**; in an embodiment, the broadcast is directed only to the other wireless sensor nodes **102** within the cluster. In an embodiment, behavior description module **110** is arranged to provide the description of its expected behaviors through an application programming interface (API); in an embodiment, only the other wireless sensor nodes **102** within a cluster have access to or may successfully receive data from the API of another wireless sensor node **102** within the cluster.

In an embodiment, wireless sensor node **102** and/or one or more sensors **104** are configurable. In such embodiments, behavior description module **110** is also configurable to reflect the expected behaviors of the new configuration of wireless sensor node **102** and/or one or more sensors **104**.

In an embodiment, wireless sensor node **102** includes behavior observation module **112**. In an embodiment, behavior observation module **112** is arranged to operate only when the wireless sensor node **102** is the leader node of its cluster of wireless sensor nodes **102**.

In an embodiment, behavior observation module **112** is arranged to detect a compromised wireless sensor node **102** within the cluster by receiving descriptions of the expected behaviors of each wireless sensor nodes **102** within the cluster, observing behaviors (e.g., communications) of the wireless sensor nodes **102** within the cluster, and identifying anomalies in communications of suspected wireless sensor nodes **102** by comparing the expected behaviors with the observed behaviors.

In an embodiment, behavior observation module **112** utilizes one or more machine learning algorithms to identify anomalies in communications of suspected wireless sensor nodes **102**. The machine learning algorithm uses one or more statistical models (e.g., topic models) in its analyses of wireless sensor node **102** communications. Some statistical models used by the machine learning algorithm include, but are not limited to, an amount or degree of deviation from the description of expected behavior for the analyzed wireless sensor node **102**, a proximity of the analyzed wireless sensor node **102** to similar wireless sensor nodes **102**, the number of and/or the nature of attempts by the analyzed wireless sensor node **102** to probe other wireless sensor nodes **102**, and the number and the type of ports open or closed on the analyzed wireless sensor node **102**.

In an embodiment, behavior observation module **112** is arranged to calculate a threat level of an analyzed wireless sensor node **102** by weighing at least one of several factors, including but not limited to, an amount or degree of deviation from the description of expected behavior for the analyzed wireless sensor node **102**, a proximity of the analyzed wireless sensor node **102** to similar wireless sensor nodes **102**, the number of and/or the nature of attempts by the analyzed wireless sensor node **102** to probe other wireless sensor nodes **102**; and the number and the type of ports open or closed on the analyzed wireless sensor node **102**. In an embodiment, threat level is measured on a variable scale rather than simply binary (e.g., compromised or uncompromised). In an embodiment, behavior observation module **112** determines that the analyzed wireless sensor node **102** has

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been compromised based on the calculated threat level for the analyzed wireless sensor node **102**.

In an embodiment, wireless sensor node **102** includes a mitigation module **114**. In an embodiment, mitigation module **114** is arranged to prevent a compromised wireless sensor node **102** from compromising other wireless sensor nodes **102** in the cluster. In an embodiment, mitigation module **114** is arranged to operate only when the wireless sensor node **102** is the leader node of its cluster of wireless sensor nodes **102**.

In an embodiment, mitigation module **114** is arranged to prevent a compromised wireless sensor node **102** from compromising other wireless sensor nodes **102** in the cluster by refusing to transmit some or all communications generated by or to be delivered to the compromised wireless sensor node **102**. In an embodiment, mitigation module **114** is arranged to prevent a compromised wireless sensor node **102** from compromising other wireless sensor nodes **102** in the cluster by forcing the compromised wireless sensor node **102** to reset itself to an uncompromised state (e.g., factory reset).

In an embodiment, a suspected wireless sensor node **102** that has been determined to be compromised may periodically be reevaluated. In an example, the revaluation may be undertaken by a third-party entity device. Such a reevaluation may ascertain whether the suspected wireless sensor node **102** is compromised via standard threat detection mechanisms. If the suspected wireless sensor node **102** passes the reevaluation, the aberrant behavior may be attributed to proper emergent behavior based on, for example, changed conditions.

In an embodiment, a suspected wireless sensor node **102** that has been determined to be compromised may object to this determination. In an embodiment, the objection by suspected wireless sensor node **102** triggers a proof operation. In an embodiment, the proof operation includes the leader node of the cluster requesting a current description of the expected behaviors of suspected wireless sensor node **102** and comparing the current description of expected behavior of suspected wireless sensor node **102** to the previous description of expected behavior of suspected wireless sensor node **102**; if a difference is detected between the current and previous description of expected behavior, the leader node reanalyzes the behavior of suspected wireless sensor node **102** (which lead to the determination that suspected wireless sensor node **102** was compromised) in light of the current description of expected behavior. In an embodiment, if the reanalysis of the behavior of suspected wireless sensor node **102** results in a determination that suspected wireless sensor node **102** is not compromised, the mitigation module **114** clears suspected wireless sensor node **102** of its "compromised" status, and allows suspected wireless sensor node **102** to continue operating.

FIG. **2** is a flowchart illustrating a process **200** performed by a wireless sensor node (e.g., wireless sensor node **102**, described above with respect to FIG. **1**) within a wireless sensor network employing cooperative security, in accordance with some example embodiments. In an embodiment, wireless sensor node **102** organizes a cluster of wireless sensor nodes **102** (including itself) by cooperating with other wireless sensor nodes **102** in the wireless network (operation **202**).

In an embodiment, wireless sensor node **102** cooperates with the other wireless sensor nodes **102** in the cluster to select a leader node for the cluster (operation **204**).

In an embodiment, wireless sensor node **102** describes the behaviors that are to be expected for wireless sensor node **102**, and makes its behavior descriptions available to the other wireless sensor nodes **102** in its cluster (operation **206**).

In an embodiment where wireless sensor node **102** is the leader node of its cluster, wireless sensor node **102** analyzes the actual behaviors of the other wireless sensor nodes **102** in its cluster, and detects a compromised wireless sensor node **102** by comparing the actual behavior of the wireless sensor node **102** to the description of the expected behavior for wireless sensor node **102** (operation **208**).

In an embodiment where wireless sensor node **102** is the leader node of its cluster, wireless sensor node **102** prevents a compromised wireless sensor node **102** from compromising the other wireless sensor nodes **102** in its cluster (operation **210**).

FIG. **3** is a flowchart illustrating a process **300** performed by an upstream cluster in analyzing communications from downstream clusters, in accordance with some example embodiments. An upstream cluster (e.g., a cluster that is closer to a destination where data is to be sent) is "higher" in the hierarchy than a downstream cluster (e.g., a cluster that is further away from a destination where data is to be sent). In an embodiment where wireless sensor node **102** is its cluster's leader node, the wireless sensor node **102** performs an "inter-cluster" health check for the cluster by sharing with its neighbor cluster(s) the descriptions of the expected behaviors of the nodes in its cluster. The neighbor cluster(s) then analyze(s) the actual behavior of the cluster and detects the cluster as compromised by comparing the actual behavior of the cluster to the description of the expected behavior for cluster, similar to the "intra-cluster" health checks performed by a leader node within its own cluster. If a neighbor cluster determines the cluster to be compromised, the neighbor cluster performs "inter-cluster" mitigation, similar to the "intra-cluster" mitigation performed by a leader node within its own cluster.

In an embodiment, clusters of wireless sensor nodes **102** within the wireless network organize themselves into a "cluster of clusters" or "super cluster" in the same way that wireless sensor nodes **102** organize themselves into clusters. In an embodiment, the clustering module **106** and leader selection module **108** of the leader node of the cluster cooperates with the clustering modules **106** and leader selection modules **108** of the leader nodes of other clusters to organize into a cluster of clusters. In an embodiment, this process is recursive in that super clusters may organize with other clusters or other super clusters to form a larger super cluster.

In an embodiment, clusters are organized hierarchically. For example, the cluster hierarchy may be tree-based, linear, or some combination thereof. In an embodiment, a cluster is restricted to communicating with one or more downstream clusters and one or more upstream clusters. In an embodiment, MAC/VLAN filtering with ARP tables is used to restrict the communications of the cluster to its assigned upstream and downstream cluster(s).

In an embodiment, the upstream cluster starts the process **300** of analyzing communications from downstream clusters (operation **302**). In an embodiment, the upstream cluster obtains, from a downstream cluster, a data payload containing actual behavior for the downstream cluster (operation **304**).

In an embodiment, the upstream cluster obtains the current description of expected behavior for the downstream cluster (operation **306**). In an embodiment, the upstream cluster obtains the prior description of expected behavior for the downstream cluster (operation **308**). In an embodiment,

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the upstream cluster determines (operation **310**) whether the current description of expected behavior for the downstream cluster (obtained at operation **306**) matches the prior description of expected behavior for the downstream cluster (obtained at operation **308**).

If the current description of expected behavior for the downstream cluster matches the prior description of expected behavior for the downstream cluster, the upstream cluster proceeds to analyze (operation **312**) the data payload (obtained at operation **304**). In an embodiment, the upstream cluster utilizes one or more machine learning algorithms **330** to analyze the data payload. In an embodiment, the upstream cluster determines (operation **314**) whether the data payload contains a behavioral anomaly. In an embodiment, if an anomaly exists in the data payload, the upstream cluster considers the downstream cluster to be compromised and mitigates the compromised downstream cluster (operation **316**) and the process **300** restarts (operation **322**). In an embodiment, mitigating the downstream cluster includes causing the downstream cluster to reset itself to an uncompromised state (e.g., each cluster in and each wireless sensor node **102** in the downstream cluster is forced to reset to an uncompromised state). In an embodiment, if an anomaly does not exist in the data payload, the upstream cluster accepts the data payload and passes the data payload upstream to its upstream cluster.

In an embodiment, if the upstream cluster determines (operation **310**) that the current description of expected behavior for the downstream cluster does not match the prior description of expected behavior for the downstream cluster, the upstream cluster determines (operation **320**) the type of change in the current description of expected behavior. In an embodiment, if the type of change is a data boundary change (e.g., a range value for a data parameter has changed), the upstream cluster causes the current description of expected behavior for the downstream cluster to be stored, accepts the data payload and passes the data payload upstream to its upstream cluster (operation **318**), and restarts process **300** (operation **322**). In an embodiment, if the type of change involves port behavior of the downstream cluster, the upstream cluster considers the downstream cluster to be compromised and mitigates the compromised downstream cluster (operation **316**) and the process **300** restarts (operation **322**).

An additional approach for anomaly and threat detection is to use lockstep voting. For example, in 2-in-3 lockstep voting, leaders of three clusters compare their data and vote. If measurements from only two clusters are similar, then the third cluster is determined to have an anomaly. The cluster with the anomaly will then be monitored by the other two clusters to determine whether the anomaly represents a one-time error or a compromised cluster. In some such embodiments, the cardinality (e.g., quantity of nodes) for each cluster is limited to a small quantity of nodes to allow such functionality. In an embodiment, the voting is performed by all three cluster receiving data from the other two clusters, computing the measurements, and then exchanging their findings; the two clusters that match are then allowed to report to an upstream cluster.

FIG. **4** is an illustration of a machine learning process **400** for observing behavior of wireless sensor nodes **102** within a cluster **402** to develop a model of expected behavior for the wireless sensor nodes **102** within the cluster **402**, in accordance with some example embodiments.

In an embodiment, when a wireless sensor node **102** within a cluster **402** is the leader node, machine learning algorithm **330** within wireless sensor node **102** enters training mode **404**. In an embodiment, machine learning algorithm **330** obtains descriptions of expected behaviors from the wireless sensor nodes **102** within its cluster (operation **406**). In an embodiment, machine learning algorithm **330** observes the network behaviors of each wireless sensor node **102** within its cluster by storing the data transmitted from or to each wireless sensor node **102** within its cluster (operation **408**).

In an embodiment, machine learning algorithm **330** proceeds to perform data analysis (operation **410**) on the descriptions of expected behaviors (obtained at operation **406**) and the stored data transmissions (obtained at operation **408**). In an embodiment, the data analysis (operation **410**) includes classification (operation **412**) of samples from the stored data transmissions. In an embodiment, the machine learning algorithm **330** uses one or more statistical models **414** in its data analysis. Some statistical models used by the machine learning algorithm include, but are not limited to, an amount or degree the data transmissions of the analyzed wireless sensor node **102** deviate from the description of expected behavior for the analyzed wireless sensor node **102**, a proximity of the analyzed wireless sensor node **102** to similar wireless sensor nodes **102**, the number of and/or the nature of attempts by the analyzed wireless sensor node **102** to probe other wireless sensor nodes **102**, the number and the type of ports open or closed on the analyzed wireless sensor node **102**, and the power recycle for analyzed wireless sensor node **102**.

In an embodiment, after the data analysis (operation **410**) is complete, machine learning algorithm **330** stores the range boundaries (operation **416**) output by the data analysis, and exits training mode **404**.

FIG. **5** illustrates a block diagram of an example machine **500** upon which any one or more of the techniques (e.g., methodologies) discussed herein may perform. In an embodiment, the machine **500** is connected (e.g., networked) to other machines. In a networked deployment, the machine **500** may operate in the capacity of a server machine, a client machine, or both a client machine and a server machine in server-client network environments. In an embodiment, the machine **500** acts as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. In an embodiment, machine **500** is a network router, switch, or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

Examples, as described herein, may include, or may operate by, logic or a number of components, or mechanisms. Circuit sets are a collection of circuits implemented in tangible entities that include hardware (e.g., simple circuits, gates, logic, etc.). Circuit set membership may be flexible over time and underlying hardware variability. Circuit sets include members that may perform, alone or in combination, specified operations when operating. In an example, hardware of the circuit set may be immutably designed to carry out a specific operation (e.g., hardwired). In an example, the hardware of the circuit set may include variably connected physical components (e.g., execution units, transistors, simple circuits, etc.) including a machine-readable medium physically modified (e.g., magnetically, electrically, moveable placement of invariant massed par-

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ticles, etc.) to encode instructions of the specific operation. In connecting the physical components, the underlying electrical properties of a hardware constituent are changed, for example, from an insulator to a conductor or vice versa. The instructions enable embedded hardware (e.g., the execution units or a loading mechanism) to create members of the circuit set in hardware via the variable connections to carry out portions of the specific operation when in operation. Accordingly, the machine-readable medium is communicatively coupled to the other components of the circuit set member when the device is operating. In an example, any of the physical components may be used in more than one member of more than one circuit set. For example, under operation, execution units may be used in a first circuit of a first circuit set at one point in time and reused by a second circuit in the first circuit set, or by a third circuit in a second circuit set at a different time.

Machine (e.g., computer system) **500** may include a hardware processor **502** (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory **504** and a static memory **506**, some or all of which may communicate with each other via an interlink (e.g., bus) **508**. The machine **500** may further include a display device **510**, an input device **512** (e.g., buttons, switches, a keyboard, etc.), and a user interface (UI) navigation device **514** (e.g., a pointing stick, an isometric joystick or other isometric device, etc.). In an embodiment, the display device **510**, input device **512**, and UI navigation device **514** may be a touch screen display. The machine **500** may additionally include a storage device (e.g., drive unit) **516**, a signal generation device **518** (e.g., a speaker), a network interface device **520**, and one or more sensors **521**, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine **500** may include an output controller **528**, such as a serial (e.g., universal serial bus (USB), parallel or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

The storage device **516** may include a machine-readable medium **522**, on which is stored one or more sets of data structures or instructions **524** (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions **524** may also reside, completely or at least partially, within the main memory **504**, within static memory **506**, or within the hardware processor **502** during execution thereof by the machine **500**. In an example, one or any combination of the hardware processor **502**, the main memory **504**, the static memory **506**, or the storage device **516** may constitute machine-readable media.

Although the machine-readable medium **522** is illustrated as a single medium, the term "machine-readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) arranged to store the one or more instructions **524**.

The term "machine-readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine **500** and that cause the machine **500** to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine-readable medium examples may include solid-state memories, and optical and magnetic media. In an example, a massed machine-readable medium comprises a machine-readable medium with a plurality of particles having invariant (e.g., rest) mass. Accordingly, massed machine-readable media are not transitory propagating signals. Specific examples of massed machine-readable media may include non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks.

The instructions **524** may further be transmitted or received over a communications network **526** using a transmission medium via the network interface device **520** utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®). IEEE 802.15.4 family of standards, IEEE 802.15.1 family of standards (known as Bluetooth®), peer-to-peer (P2P) networks, among others. In an embodiment, the network interface device **520** may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) and/or one or more antennas to connect to the communications network **526**. In an example, the network interface device **520** may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine **500**, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

The various operations of the example methods described herein may be performed, at least partially, by one or more processors that are temporarily arranged (e.g., by software instructions) or permanently arranged to perform the relevant operations. Whether temporarily or permanently arranged, such processors may constitute processor-implemented modules or objects that operate to perform one or more operations or functions. The modules and objects referred to herein, in some example embodiments, may comprise processor-implemented modules and/or objects.

Similarly, the methods described herein may be at least partially processor-implemented. For example, at least some of the operations of a method may be performed by one or more processors or processor-implemented modules. The performance of certain operations may be distributed among the one or more processors, not only residing within a single machine or computer, but also deployed across a number of machines or computers. In some example embodiments, the processor or processors may be located in a single location (e.g., within a home environment, an office environment, at a server farm, etc.), while in other embodiments, the processors may be distributed across a number of locations.

The one or more processors may also operate to support performance of the relevant operations in a "cloud computing" environment or within the context of software as a service (SaaS). For example, at least some of the operations may be performed by a group of computers (as examples of

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machines including processors), these operations being accessible via a network (e.g., the Internet) and via one or more appropriate interfaces (e.g., Application Program Interfaces (APIs)).

ADDITIONAL NOTES & EXAMPLE EMBODIMENTS

Example 1 includes subject matter (such as a device, apparatus, or machine) comprising: a sensor to acquire data; a clustering module to organize the wireless device into a cluster with other wireless devices from a plurality of wireless devices in a wireless network; a leader selection module to cooperate with the other wireless devices in the cluster to select a leader for the cluster; a behavior description module to describe expected behaviors of the wireless device; a behavior observation module to detect a compromised wireless device within the cluster; and a mitigation module to prevent the compromised wireless device from compromising another wireless device.

In Example 2, the subject matter of Example 1 may include, wherein the behavior observation module of the wireless device is to detect while the wireless device is the leader of the cluster.

In Example 3, the subject matter of any one of Examples 1 to 2 may include, wherein the mitigation module of the wireless device is to prevent the compromised wireless device from compromising another wireless device while the wireless device is the leader of the cluster.

In Example 4, the subject matter of any one of Examples 1 to 3 may include, wherein to prevent the compromised wireless device from compromising another wireless device includes the mitigation module to instruct the other wireless devices in the cluster to select a new leader for the cluster in response to being compromised.

In Example 5, the subject matter of any one of Examples 1 to 4 may include, wherein to detect a compromised wireless device includes the behavior observation module to: analyze communications of a suspected wireless device; and identify anomalies in the communications of the suspected wireless device.

In Example 6, the subject matter of any one of Examples 1 to 5 may include, wherein to identify anomalies in communications of the suspected wireless device includes the behavior observation module to utilize a machine learning algorithm.

In Example 7, the subject matter of any one of Examples 1 to 6 may include, wherein the behavior observation module is to calculate a threat level of the suspected wireless device based on at least one of: amount of deviation from described expected behavior of the suspected wireless device; proximity of the suspected wireless device to similar wireless devices; attempts by the suspected wireless device to probe other wireless devices; and number and type of ports open on the suspected wireless device.

In Example 8, the subject matter of any one of Examples 1 to 7 may include, wherein the behavior observation module is to determine the suspected wireless device as compromised based on the calculated threat level of the suspected wireless device.

In Example 9, the subject matter of any one of Examples 1 to 8 may include, wherein the leader of the cluster is to proxy all communications that are to be transmitted by or to be received by any other wireless device in the cluster.

In Example 10, the subject matter of any one of Examples 1 to 9 may include, wherein the mitigation module of the wireless device is to prevent the compromised wireless device from compromising another wireless device by refusing to transmit a communication generated by the compromised wireless device.

In Example 11, the subject matter of any one of Examples 1 to 10 may include, wherein the mitigation module of the wireless device is to prevent the compromised wireless device from compromising another wireless device by refusing to transmit a communication to be delivered to the compromised wireless device.

In Example 12, the subject matter of any one of Examples 1 to 11 may include, wherein the mitigation module of the wireless device is to prevent the compromised wireless device from compromising another wireless device by forcing the compromised wireless device to reset itself to an uncompromised state.

In Example 13, the subject matter of any one of Examples 1 to 12 may include, wherein the cluster comprises wireless devices of a similar type.

In Example 14, the subject matter of any one of Examples 1 to 13 may include, wherein the wireless devices in the cluster are redundant.

In Example 15, the subject matter of any one of Examples 1 to 14 may include, wherein the plurality of wireless devices are organized into a plurality of clusters.

In Example 16, the subject matter of any one of Examples 1 to 15 may include, wherein each cluster is to perform health checks by sharing, with its neighbor clusters, its described expected behaviors and its sensor data.

In Example 17, the subject matter of any one of Examples 1 to 16 may include, wherein a subset of clusters within the plurality of clusters are organized into a cluster of clusters.

In Example 18, the subject matter of any one of Examples 1 to 17 may include, wherein a selected cluster within the plurality of clusters is to: create a super cluster by combining the selected cluster with other clusters from the plurality of clusters; cooperate with the other clusters in the super cluster to select a leader cluster for the super cluster; describe expected behaviors of the selected cluster; detect a compromised cluster within the super cluster; and prevent the compromised cluster from compromising another cluster.

In Example 19, the subject matter of any one of Examples 1 to 18 may include, wherein the plurality of clusters are organized hierarchically.

In Example 20, the subject matter of any one of Examples 1 to 19 may include, wherein an upstream cluster is hierarchically higher than a downstream cluster.

In Example 21, the subject matter of any one of Examples 1 to 20 may include, wherein the behavior description module is to describe expected behaviors of the wireless device using XML.

In Example 22, the subject matter of any one of Examples 1 to 21 may include, wherein the behavior description module is to broadcast the described expected behaviors of the wireless device.

In Example 23, the subject matter of any one of Examples 1 to 22 may include, wherein the behavior description module is to provide, through an application programming interface, the described expected behaviors of the wireless device.

In Example 24, the subject matter of any one of Examples 1 to 23 may include, wherein the behavior description module is to describe expected behaviors of the wireless device by describing a parameter to be transmitted by or to be received by the wireless device, the parameter a name, a data type; and a range including: a bottom value, indicating

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a lowest value of the data type allowed for the parameter; and a top value, indicating a highest value of the data type allowed for parameter.

In Example 25, the subject matter of any one of Examples 1 to 24 may include, wherein the wireless device is configurable by an end customer.

Example 26 includes subject matter (such as a method, means for performing acts, machine readable medium including instructions that when performed by a machine cause the machine to performs acts, or an apparatus to perform) for securing a wireless sensor network comprising a plurality of wireless devices, the method performed by a wireless device in the plurality, the method comprising: organizing the wireless device into a cluster with other wireless devices from the plurality; cooperating with the other wireless devices in the cluster to select a leader for the cluster; describing expected behaviors of the wireless device; detecting a compromised wireless device within the cluster; and preventing the compromised wireless device from compromising another wireless device.

In Example 27, the subject matter of Example 26 may include, wherein the detecting is performed while the wireless device is the leader of the cluster.

In Example 28, the subject matter of any one of Examples 26 to 27 may include, wherein the preventing is performed while the wireless device is the leader of the cluster.

In Example 29, the subject matter of any one of Examples 26 to 28 may include, wherein preventing the compromised wireless device from compromising another wireless device includes instructing the other wireless devices in the cluster to select a new leader for the cluster in response to being compromised.

In Example 30, the subject matter of any one of Examples 26 to 29 may include, wherein detecting a compromised wireless device within the cluster includes: analyzing communications of a suspected wireless device; and identifying anomalies in the communications of the suspected wireless device.

In Example 31, the subject matter of any one of Examples 26 to 30 may include, wherein identifying anomalies in communications of the suspected wireless device includes utilizing a machine learning algorithm.

In Example 32, the subject matter of any one of Examples 26 to 31 may include, wherein detecting includes calculating a threat level of the suspected wireless device based on at least one of: amount of deviation from described expected behavior of the suspected wireless device; proximity of the suspected wireless device to similar wireless devices; attempts by the suspected wireless device to probe other wireless devices; and number and type of ports open on the suspected wireless device.

In Example 33, the subject matter of any one of Examples 26 to 32 may include, wherein detecting includes determining the suspected wireless device is compromised based on the calculated threat level of the suspected wireless device.

In Example 34, the subject matter of any one of Examples 26 to 33 may include, wherein the leader of the cluster proxies all communications that are to be transmitted by or to be received by any other wireless device in the cluster.

In Example 35, the subject matter of any one of Examples 26 to 34 may include, wherein preventing the compromised wireless device from compromising another wireless device includes refusing to transmit a communication generated by the compromised wireless device.

In Example 36, the subject matter of any one of Examples 26 to 35 may include, wherein preventing the compromised wireless device from compromising another wireless device includes refusing to transmit a communication to be delivered to the compromised wireless device.

In Example 37, the subject matter of any one of Examples 26 to 36 may include, wherein preventing the compromised wireless device from compromising another wireless device includes forcing the compromised wireless device to reset itself to an uncompromised state.

In Example 38, the subject matter of any one of Examples 26 to 37 may include, wherein the cluster comprises wireless devices of a similar type.

In Example 39, the subject matter of any one of Examples 26 to 38 may include, wherein the wireless devices in the cluster are redundant.

In Example 40, the subject matter of any one of Examples 26 to 39 may include, wherein the plurality of wireless devices are organized into a plurality of clusters.

In Example 41, the subject matter of any one of Examples 26 to 40 may include, wherein each cluster performs health checks by sharing, with its neighbor clusters, its described expected behaviors and its sensor data.

In Example 42, the subject matter of any one of Examples 26 to 41 may include, wherein a subset of clusters within the plurality of clusters are organized into a cluster of clusters.

In Example 43, the subject matter of any one of Examples 26 to 42 may include, wherein a selected cluster within the plurality of clusters performs operations creating a super cluster by combining the selected cluster with other clusters from the plurality of clusters; cooperating with the other clusters in the super cluster to select a leader cluster for the super cluster; describing expected behaviors of the selected cluster; detecting a compromised cluster within the super cluster; and preventing the compromised cluster from compromising another cluster.

In Example 44, the subject matter of any one of Examples 26 to 43 may include, wherein the plurality of clusters are organized hierarchically.

In Example 45, the subject matter of any one of Examples 26 to 44 may include, wherein an upstream cluster is hierarchically higher than a downstream cluster.

In Example 46, the subject matter of any one of Examples 26 to 45 may include, wherein the wireless device describes its expected behaviors using XML.

In Example 47, the subject matter of any one of Examples 26 to 46 may include, wherein the wireless device broadcasts its description of expected behavior.

In Example 48, the subject matter of any one of Examples 26 to 47 may include, wherein the wireless device provides its description of expected behavior through an application programming interface.

In Example 49, the subject matter of any one of Examples 26 to 48 may include, wherein the description of expected behavior of the wireless device includes a parameter to be transmitted by or to be received by the wireless device, the parameter a name; a data type; and a range including: a bottom value, indicating a lowest value of the data type allowed for the parameter; and a top value, indicating a highest value of the data type allowed for parameter.

In Example 50, the subject matter of any one of Examples 26 to 49 may include, wherein the wireless device is configurable by an end customer.

Example 51 includes at least one machine-readable medium including instructions, which when executed by a machine, cause the machine to perform any of the Examples 26-50.

Example 52 includes an apparatus comprising means for performing any of the Examples 26-50.

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Example 53 includes subject matter (such as a device, apparatus, or machine) for securing a wireless sensor network comprising a plurality of wireless devices, the device comprising: means for organizing the wireless device into a cluster with other wireless devices from the plurality; means for cooperating with the other wireless devices in the cluster to select a leader for the cluster; means for describing expected behaviors of the wireless device; means for detecting a compromised wireless device within the cluster; and means for preventing the compromised wireless device from compromising another wireless device.

In Example 54, the subject matter of Example 53 may include, wherein the means for detecting operates while the wireless device is the leader of the cluster.

In Example 55, the subject matter of any one of Examples 53 to 54 may include, wherein the means for preventing operates while the wireless device is the leader of the cluster.

In Example 56, the subject matter of any one of Examples 53 to 55 may include, wherein the means for preventing the compromised wireless device from compromising another wireless device includes means for instructing the other wireless devices in the cluster to select a new leader for the cluster in response to being compromised.

In Example 57, the subject matter of any one of Examples 53 to 56 may include, wherein the means for detecting a compromised wireless device within the cluster includes: means for analyzing communications of a suspected wireless device; and means for identifying anomalies in the communications of the suspected wireless device.

In Example 58, the subject matter of any one of Examples 53 to 57 may include, wherein the means for identifying anomalies in communications of the suspected wireless device includes means for utilizing a machine learning algorithm.

In Example 59, the subject matter of any one of Examples 53 to 58 may include, wherein the means for detecting includes means for calculating a threat level of the suspected wireless device based on at least one of: amount of deviation from described expected behavior of the suspected wireless device; proximity of the suspected wireless device to similar wireless devices; attempts by the suspected wireless device to probe other wireless devices; and number and type of ports open on the suspected wireless device.

In Example 60, the subject matter of any one of Examples 53 to 59 may include, wherein the means for detecting includes means for determining the suspected wireless device is compromised based on the calculated threat level of the suspected wireless device.

In Example 61, the subject matter of any one of Examples 53 to 60 may include, wherein the leader of the cluster includes means for proxying all communications that are to be transmitted by or to be received by any other wireless device in the cluster.

In Example 62, the subject matter of any one of Examples 53 to 61 may include, wherein the means for preventing the compromised wireless device from compromising another wireless device includes means for refusing to transmit a communication generated by the compromised wireless device.

In Example 63, the subject matter of any one of Examples 53 to 62 may include, wherein the means for preventing the compromised wireless device from compromising another wireless device includes means for refusing to transmit a communication to be delivered to the compromised wireless device.

In Example 64, the subject matter of any one of Examples 53 to 63 may include, wherein the means for preventing the compromised wireless device from compromising another wireless device includes means for forcing the compromised wireless device to reset itself to an uncompromised state.

In Example 65, the subject matter of any one of Examples 53 to 64 may include, wherein the cluster comprises wireless devices of a similar type.

In Example 66, the subject matter of any one of Examples 53 to 65 may include, wherein the wireless devices in the cluster are redundant.

In Example 67, the subject matter of any one of Examples 53 to 66 may include, wherein the plurality of wireless devices are organized into a plurality of clusters.

In Example 68, the subject matter of any one of Examples 53 to 67 may include, wherein each cluster includes means for performing health checks by sharing, with its neighbor clusters, its described expected behaviors and its sensor data.

In Example 69, the subject matter of any one of Examples 53 to 68 may include, wherein a subset of clusters within the plurality of clusters are organized into a cluster of clusters.

In Example 70, the subject matter of any one of Examples 53 to 69 may include, wherein a selected cluster within the plurality of clusters includes: means for creating a super cluster by combining the selected cluster with other clusters from the plurality of clusters; means for cooperating with the other clusters in the super cluster to select a leader cluster for the super cluster; means for describing expected behaviors of the selected cluster; means for detecting a compromised cluster within the super cluster; and means for preventing the compromised cluster from compromising another cluster.

In Example 71, the subject matter of any one of Examples 53 to 70 may include, wherein the plurality of clusters are organized hierarchically.

In Example 72, the subject matter of any one of Examples 53 to 71 may include, wherein an upstream cluster is hierarchically higher than a downstream cluster.

In Example 73, the subject matter of any one of Examples 53 to 72 may include, wherein the wireless device includes means for describing its expected behaviors using XML.

In Example 74, the subject matter of any one of Examples 53 to 73 may include, wherein the wireless device includes means for broadcasting its description of expected behavior.

In Example 75, the subject matter of any one of Examples 53 to 74 may include, wherein the wireless device includes means for providing its description of expected behavior through an application programming interface.

In Example 76, the subject matter of any one of Examples 53 to 75 may include, wherein the description of expected behavior of the wireless device includes a parameter to be transmitted by or to be received by the wireless device, the parameter a name; a data type; and a range including: a bottom value, indicating a lowest value of the data type allowed for the parameter; and a top value, indicating a highest value of the data type allowed for parameter.

In Example 77, the subject matter of any one of Examples 53 to 76 may include, wherein the wireless device includes means for being configured by an end customer.

Example 78 includes a wireless network including a plurality of wireless devices according to any of the devices of claims **1-25**.

Conventional terms in the fields of computer networking and computer systems have been used herein. The terms are known in the art and are provided only as a non-limiting example for convenience purposes. Accordingly, the interpretation of the corresponding terms in the claims, unless stated otherwise, is not limited to any particular definition.

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Thus, the terms used in the claims should be given their broadest reasonable interpretation.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement that is calculated to achieve the same purpose may be substituted for the specific embodiments shown. Many adaptations will be apparent to those of ordinary skill in the art. Accordingly, this application is intended to cover any adaptations or variations.

The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments that may be practiced. These embodiments are also referred to herein as "examples." Such examples may include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

Method examples described herein may be machine or computer-implemented at least in part. Some examples may include a machine-readable medium or machine-readable medium encoded with instructions operable to configure an electronic device to perform methods as described in the above examples. An implementation of such methods may include code, such as microcode, assembly language code, a higher-level language code, or the like. Such code may include machine-readable instructions for performing various methods. The code may form portions of computer program products. Further, in an example, the code may be tangibly stored on one or more volatile, non-transitory, or non-volatile tangible machine-readable media, such as during execution or at other times. Examples of these tangible machine-readable media may include, but are not limited to, hard disks, removable magnetic disks, removable optical disks (e.g., compact disks and digital video disks), magnetic cassettes, memory cards or sticks, random access memories (RAMs), read-only memories (ROMs), and the like.

The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with each other. Other embodiments may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is provided to comply with 37 C.F.R. § 1.72(b), to allow the reader to quickly ascertain the nature of the technical disclosure and is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

In this Detailed Description, various features may have been grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter may lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment, and it is contemplated that such embodiments may be combined with each other in various combinations or permutations. The scope of the embodiments should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. A device for cooperative security in a wireless network, the device comprising:

at least one processor; and

memory including instructions that, when executed by the at least one processor, cause the at least one processor to:

organize a plurality of wireless devices into a first wireless device cluster, wherein the first cluster is a member of a plurality of wireless device clusters, and wherein the device is a member of the first wireless device cluster;

initiate selection of a leader device for the first wireless device cluster;

receive an identification of the leader device for the first wireless device cluster;

establish a proxy connection to the leader device, wherein the proxy connection is used by the leader device to process all data transmissions between the device and the other devices of the plurality of wireless device clusters, and wherein the data transmissions are monitored by the leader device to verify an operational state of the first wireless device cluster; and

receive a reset command from the leader device to place the device in an uncompromised state based on a determination, by the leader device, that the device has entered a compromised state, wherein the reset command is a command to initiate a factory reset of the device.

2. The device of claim **1**, further comprising instructions to:

identify the plurality of wireless devices based on proximity of members of the plurality of wireless devices to the device, wherein the organization of the plurality of devices into the first wireless device cluster is based on the identification of the proximity of the members of the plurality of wireless devices.

3. The device of claim **1**, further comprising instructions to:

identify the plurality of wireless devices based on a device type;

wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the device type.

4. The device of claim **1**, further comprising instructions to:

identify the plurality of wireless devices based a level of redundancy for the first wireless device cluster, wherein the organization of the plurality of wireless devices into

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the first wireless device cluster is based on identification of the level of redundancy.

5. The device of claim 1, further comprising instructions to:

identify the plurality of wireless devices based on a shared capability, wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the shared capability.

6. The device of claim 1, further comprising instructions to:

receive, from the leader device, a command to cease data transmissions, wherein the command to cease data transmissions is transmitted based on the device being identified as a compromised wireless device, wherein the leader device identifies the device as compromised based on the device operating outside an unexpected behavior as indicated in the monitored data transmissions, wherein the operation outside the expected behavior causes the leader device to identify the first wireless device cluster as compromised, and wherein the leader device communicates with a second wireless device cluster leader to verify the first wireless device cluster is compromised.

7. The device of claim 6, wherein the expected behavior describes one or more data parameters to be communicated between the compromised wireless device and the plurality of wireless device clusters.

8. The device of claim 1, wherein the first wireless device cluster uses a tree-based cluster hierarchy.

9. The device of claim 1, wherein the first wireless device cluster uses a linear cluster hierarchy.

10. At least one non-transitory machine-readable medium including instructions for cooperative security in a wireless network that, when executed by a machine, cause the machine to perform operations to:

organize a plurality of wireless devices into a first wireless device cluster, wherein the first cluster is a member of a plurality of wireless device clusters;

initiate selection of a leader device for the first wireless device cluster;

receive an identification of the leader device for the first wireless device cluster;

establish a proxy connection to the leader device, wherein the proxy connection is used by the leader device to process all data transmissions between a wireless device of the first wireless device cluster and the other devices of the plurality of wireless device clusters, and wherein the data transmissions are monitored by the leader device to verify an operational state of the first wireless device cluster; and

transmit a reset command to the wireless device to place the wireless device in an uncompromised state based on a determination, by the leader device, that the wireless device has entered a compromised state, wherein the reset command is a command to initiate a factory reset of the device.

11. The at least one machine-readable medium of claim 10, further comprising instructions to:

identify the plurality of wireless devices based on proximity of members of the plurality of wireless devices, wherein the organization of the plurality of devices into the first wireless device cluster is based on the identification of the proximity of the members of the plurality of wireless devices.

12. The at least one machine-readable medium of claim 10, further comprising instructions to:

identify the plurality of wireless devices based on a device type;

wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the device type.

13. The at least one machine-readable medium of claim 10, further comprising instructions to:

identify the plurality of wireless devices based a level of redundancy for the first wireless device cluster, wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the level of redundancy.

14. The at least one machine-readable medium of claim 10, further comprising instructions to:

identify the plurality of wireless devices based on a shared capability, wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the shared capability.

15. The at least one machine-readable medium of claim 10, further compromising instructions to:

receive, from the leader device, a command to cease data transmissions, wherein the command to cease data transmissions is transmitted based on the wireless device being identified as a compromised wireless device, wherein the leader device identifies the wireless device as compromised based on the wireless device operating outside an unexpected behavior as indicated in the monitored data transmissions, wherein the operation outside the expected behavior causes the leader device to identify the first wireless device cluster as compromised, and wherein the leader device communicates with a second wireless device cluster leader to verify the first wireless device cluster is compromised.

16. The at least one machine-readable medium of claim 15, wherein the expected behavior describes one or more data parameters to be communicated between the wireless device and the plurality of wireless device clusters.

17. The at least one machine-readable medium of claim 10, wherein the first wireless device cluster uses a tree-based cluster hierarchy.

18. A method for cooperative security in a wireless network, the method comprising:

organizing a plurality of wireless devices into a first wireless device cluster, wherein the first cluster is a member of a plurality of wireless device clusters;

initiating selection of a leader device for the first wireless device cluster;

receiving an identification of the leader device for the first wireless device cluster;

establishing a proxy connection to the leader device, wherein the proxy connection is used by the leader device to process all data transmissions between a wireless device of the first wireless device cluster and the other devices of the plurality of wireless device clusters, and wherein the data transmissions are monitored by the leader device to verify an operational state of the first wireless device cluster; and

transmitting a reset command to the wireless device to place the wireless device in an uncompromised state based on a determination, by the leader device, that the wireless device has entered a compromised state, wherein the reset command is a command to initiate a factory reset of the device.

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19. The method of claim 18, further comprising:

identifying the plurality of wireless devices based on proximity of members of the plurality of wireless devices, wherein the organization of the plurality of devices into the first wireless device cluster is based on the identification of the proximity of the members of the plurality of wireless devices.

20. The method of claim 18, further comprising:

identifying the plurality of wireless devices based on a device type; wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the device type.

21. The method of claim 18, further comprising:

identifying the plurality of wireless devices based a level of redundancy for the first wireless device cluster, wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the level of redundancy.

22. The method of claim 18, further comprising:

identifying the plurality of wireless devices based on a shared capability, wherein the organization of the plurality of wireless devices into the first wireless device cluster is based on identification of the shared capability.

23. The method of claim 18, further compromising:

receiving, from the leader device, a command to cease data transmissions, wherein the command to cease data transmissions is transmitted based on the wireless device being identified as a compromised wireless device, wherein the leader device identifies the wireless device as compromised based on the wireless device operating outside an unexpected behavior as indicated in the monitored data transmissions, wherein the operation outside the expected behavior causes the leader device to identify the first wireless device cluster as compromised, and wherein the leader device communicates with a second wireless device cluster leader to verify the first wireless device cluster is compromised.

24. The method of claim 23, wherein the expected behavior describes one or more data parameters to be communicated between the wireless device and the plurality of wireless device clusters.

25. The method of claim 18, wherein the first wireless device cluster uses a linear cluster hierarchy.

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