



## (51) International Patent Classification:

*H04W* 72/00 (2009.01)    *H04B* 7/00 (2006.01)  
*H04W* 24/02 (2009.01)    *H04W* 88/02 (2009.01)

## (21) International Application Number:

PCT/AU2011/000397

## (22) International Filing Date:

7 April 2011 (07.04.2011)

## (25) Filing Language:

English

## (26) Publication Language:

English

## (30) Priority Data:

2010901496    8 April 2010 (08.04.2010)    AU

(71) Applicant (for all designated States except US): **COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION** [AU/AU]; Limestone Avenue, Campbell, Australian Capital Territory 2612 (AU).

## (72) Inventors; and

(75) Inventors/Applicants (for US only): **RICHTER, Christian** [DE/AU]; 4/22 Holland Street, Toowong, Queensland 4066 (AU). **COLLINGS, Iain** [AU/AU]; 163 Boundary Street, Roseville Chase, New South Wales 2069 (AU). **BRUENIG, Michael** [DE/AU]; 39 Brompton Place, Brookfield, Queensland 4069 (AU). **KUSY, Branislav** [SK/AU]; 10/39 Edmondstone Street, South Brisbane, Queensland 4101 (AU). **JURDAK, Raja** [—/AU]; 212/26 Felix Street, Brisbane, Queensland 4000

(AU). **OSTRY, Diethelm** [AU/AU]; c/o CSIRO ICT Centre, Cnr Vimiera & Pembroke Roads, Marsfield, New South Wales 2122 (AU).

(74) Agent: **SHELSTON IP**; Shelston IP, Level 21, 60 Margaret Street, Sydney, New South Wales 2000 (AU).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: A LOW POWER SENSING AND COMMUNICATIONS SYSTEM AND METHOD

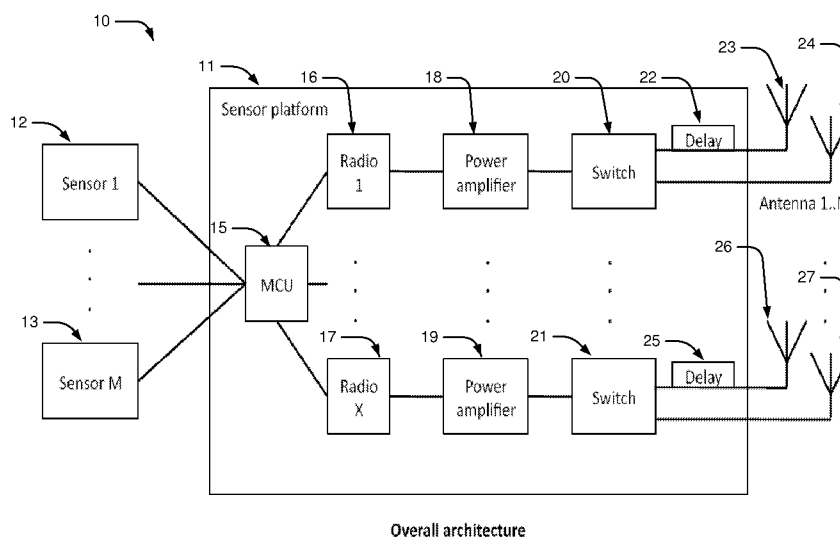


Fig. 1

(57) Abstract: A node in a wireless network, the node including: a radio frequency transmission unit for transmitting data as part of the wireless network; at least one sensor attached to the node for sensing the local environmental parameters surrounding the node; processing unit for optimizing the mode of communication by the radio frequency transmission unit based on the influence of the measured local environmental parameters.

**WO 2011/123893 A1**



---

**Published:**

— *with international search report (Art. 21(3))*

- 1 -

## A Low Power Sensing and Communications System and Method

### Field of the Invention

[0001] The present invention relates to AEEU communications and sensing the environment and, in particular, discloses a sensing environment to provide for more optimal communications in an RF network.

### Background

[0002] Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of common general knowledge in the field.

[0003] Wireless communications devices are becoming increasingly important and prevalent in modern communications systems. Unfortunately, these communication links are often unreliable, and in the large part the communication devices in the networks are non-adaptive. In adaptive systems, the adaption is often based on short-term electromagnetic parameters, that are typically measured by the communication device, such as channel state information and packet error rates.

[0004] Existing systems in wireless sensor networks are typically not adaptive. They typically rely on measurements of the channel condition. These measurements are usually short-term measurements (such as LQI/RSSI/ED which is only available after a packet has been received and relate to the time the packet has been received). The prediction of future channel conditions is thus very limited and fallback solutions may be hard to determine without testing them one by one.

[0005] Existing technology also often rely on a single receiver architectures, in some cases with multiple antennas. There are also wireless communication systems using multiple transmitters, however, these systems are usually only aimed at sending control traffic at the plethora of transmitters.

[0006] In a wireless networking environment, current technology often provides a fixed maximum link budget that can be subject to severe multipath or fading in certain environments. In such cases, the wireless communication system may loose connectivity and the network may not be operational. The current art often relies on increasing the transmission power to fix such links. However, this may not solve the communication issues in specific interference or multipath environments.

[0007] Other existing attempts to operate with specific severe interference or multipath environments often rely on changes to the channels (channel hopping). These techniques are documented at length in the IEEE standard 802.15.4e.

[0008] Some communication systems rely on adaptive decisions where each node's radio has to continuously monitor the radio channel to collect the input parameters that drive the radio

- 2 -

configuration changes. In sensor networks, it is not possible to continuously monitor the radio channel, as this would deplete node batteries quickly due to the high listening energy consumption of WSN radios.

#### Summary

5 [0009] It is an object of the present invention to provide an improved wireless communications network.

[0010] In accordance with a first aspect of the present invention, there is provided a node in a wireless network, the node including: a radio frequency transmission unit for transmitting data as part of the wireless network; at least one sensor attached to the node for sensing the local  
10 environmental parameters surrounding the node; and a processing unit for optimizing the mode of communication by the radio frequency transmission unit based on the influence of the measured local environmental parameters.

[0011] The optimizing preferably can include taking into account at least one of time of day, time of year and prior environmental modelling; in order to optimize network performance. The  
15 performance measures utilized in the optimizing can include at least one of: power usage, data rates, packet loss, packet delay, packet delay jitter, network reliability, network connectivity and network lifetime. The local environmental parameters can include at least one of: temperature, wind speed, wind direction, wind rotation, pressure, ambient light, humidity, flooding, vibration, impact, seismic activity, smoke, rain fall, rain rate or any gradients thereof.

20 [0012] The optimizing preferably can include measuring the local environmental parameters, updating a functional estimate of the relationship between these parameters and the optimal mode of communication, and selecting the mode of communication by using the measured parameters and the functional relationship.

[0013] The optimizing preferably can include optimisation of at least one of: a multiplicity of  
25 transducer elements, a multiplicity of frequency bands, a multiplicity of possible operating frequencies within the frequency bands, a multiplicity of modulation waveforms, a multiplicity of coding methods or a multiplicity of network routes.

[0014] The sensor preferably can include an infrared, acoustic, radio or other communication device. In some embodiments, the wireless network can include nodes having no sensors. The  
30 optimization information can be distributed to other nodes in the network. In some embodiments, link failures are preferably made known to the whole network to allow other nodes the evaluation of recovery strategies. In some embodiments, any derived significant statistical data can be distributed within the network to allow any node to utilize the data in determining an optimization of that node.

- 3 -

[0015] The radio frequency transmission unit preferably can include a series of omnidirectional or directional radiation antenna and the optimizing preferably can include optimizing the directional characteristics of the radiation. The sensor preferably can include line of sight sensor and the optimization preferably can include dynamically determining the line of sight characteristics between nodes. The optimizing preferably can include beam forming of the radiation pattern.

[0016] The optimizing preferably can include beam forming to avoid interference between nodes. In some embodiments, a node experiences intermittent transmission requirements and increases its priority during active transmissions. One of the optimization criteria can be the power requirements incurred during the optimization process. The beamforming can be done to allow transmission to more than one neighbouring node.

[0017] In some embodiments, the network can include multi-hops and the radio frequency transmission unit preferably can include a series of directional radiation antenna divided into at least two sets, with a first set having first optimized beam characteristics and a second set having second optimized beam characteristics with the two beam directions covering a set of nodes in the network which are preferably either equal to, overlapping or completely different to each set. In some embodiments, the network preferably can include multi-hops and a first transmission occurs to a next hop and simultaneously to an originating node.

[0018] The invention can be applied to any wireless communication standard, including but not limited to IEEE 802.11 and IEEE 802.15.4.

#### Brief Description of the Drawings

[0019] Benefits and advantages of the present invention will become apparent to those skilled in the art to which this invention relates from the subsequent description of exemplary embodiments and the appended claims, taken in conjunction with the accompanying drawings, in which:

Fig. 1 schematically illustrates the architecture of a single node;

Fig. 2 schematically illustrates the interaction of core components in the optimization process;

Fig. 3 illustrates a flow chart of an example optimization;

Fig. 4 illustrates the use of beamforming on different frequencies to cover different network areas;

Fig. 5 illustrates the use of beamforming to mitigate interference;

Fig. 6 illustrates the use of beamforming to provide simultaneous acknowledgement and delivery;

Fig. 7 illustrates an example variation of temperature with RSSI; and

Fig. 8 illustrates an example variation of humidity with RSSI.

Detailed Description

[0020] Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings.

[0021] The preferred embodiments of the present invention utilise a networks of sensors, wherein the sensors are attached to wireless communication devices that are able to adapt their communication methods based on information measured by the sensors. The communication devices are adapted based on long term sensor measurements. The measurements are taken from the environment by the sensor nodes in the network. These long-term measurements are utilised to form correlations that model the relationship between the communication link quality and the measurable environmental factors. Examples of such factors include wind speed, temperature, and humidity, amongst others. The correlation models are adaptive models and can be adapted during the network operation over time. The environmental correlation based adaption can be augmented with existing methods of adaption, including channel state information and packet error rates.

[0022] In the preferred embodiment, the signal condition is correlated with the physical signal collection from the sensors, which the node is already collecting, to drive radio configuration changes. This enables nodes to power down their radios for all the time to exploit low power listening techniques (like the Berkley MAC protocol), while adapting the radio configuration to changes in the physical environment at low energy cost with minimal neighbour interaction. Additionally, only a minimal number of fallback solutions are tested for their applicability, thus save time and energy.

[0023] In the preferred embodiment, correlations of sensed phenomena with channel condition phenomena are exploited to maximize transmission characteristics. The surroundings of the node are measured with attached sensors (to gather wind speed, humidity, temperature for example) and build on known correlations or past observed correlations of these measurements with channel condition metrics and system metrics like end-to-end delivery.

[0024] Other advantages include the ease of selecting the appropriate communication setting. For existing systems this process is usually quite complex and involves many layers of network protocols. In the preferred embodiments, the decision can be derived from easy to acquire environmental measurements that are not related to the communication device.

[0025] The disclosed embodiments are able to consider all possible parameters of the used communication devices and their communication impact in specific environments (like a specific modulation or data-rate that may cope better with humidity or other factors) to derive further optimisation. Settings adapted can include: (1) radio frequency, (2) radio frequency modulation, (3) symbols to chip mapping, (4) antenna, (5) antenna height, (6) output power; and (7) all other communication system influencing parameters.

[0026] The preferred embodiment is best described by reference to a specific example initially illustrated 10 in Fig. 1. The preferred embodiment includes both hardware and software to operate. It includes a number of wirelessly interconnected nodes or sensor platforms e.g. 11.

5 [0027] From a hardware perspective, in some embodiments, each sensor platform 11 can use a low power microcontroller 15, multiple low power RF transmitters / receivers e.g. 16, 17 and RF amplifiers e.g. 18, 19, multiple antennas e.g. 23, 24, 26, 27 for each of before mentioned receivers / transmitters including switches e.g. 20, 21 that enable a selection of 1-N antennas for each receiver / transmitter. Additionally, there may be N-1 delay circuits before N-1 antennas to allow  
10 for specific beam forming reception or transmission.

[0028] Further there are 0 to M sensors e.g. 12, 13 attached to the microcontroller 15, monitoring application specific external phenomena such as temperature, soil moisture, humidity, wind speed, etc.

15 [0029] The sensors monitor the external environment. Under varying channel conditions, the communications links may fluctuate in quality. A number of link quality aspects may be predicable. The overall system attempts to correlate fluctuations in sensor conditions with the quality of each link.

[0030] Within the purpose of sensor networks, the network is constantly measuring environmental data such as temperature, humidity, rain, hail and other environmental phenomena.  
20 To deliver this data to a central data storage and offline analysis, the nodes save the data on local memory and transmit it via a communication device to another node that is closer to the delivery endpoint. There are many algorithms for doing so – the collection tree protocol is an example.

[0031] As the data reception on the delivery endpoint (commonly known as base station) is crucial to the purpose of the network, the individual links between the nodes must be reliable.

25 [0032] Typically, networks are deployed at a certain point in time and operate well. However, in cases of severe environmental changes such as rain, storms, temperature changes and other things, the transmission between these nodes can fail due to the effects of these phenomena towards the channel quality. For example a storm may move trees to an extent that leaves obstruct the line of sight path between two nodes so that a transmission between these nodes is now impossible.

30 [0033] Other influences can be for example humidity and temperature. The influences of these effects is shown in Fig. 7 and Fig. 8. As shown in Fig. 7 and Fig. 8, the degradation of channel quality can be measured by communication device metrics like RSSI and LQI (commonly provided by off the shelf radios).

35 [0034] In the preferred embodiment, the data on reception of each packet in the network is stored with a timestamp. Correlations of this channel information to the measurements acquired on

- 6 -

attached sensors like temperature is then measured. Over longer time frames, stable correlations can form and assist with the adjustment of the communication device towards the optimal communication mode without the need to continuously measure all possible hardware configuration modes.

5 [0035] Considering different application cases where a delivery is bound to quality of service parameters such as time of arrival, maximum amount of data loss (due to transmission) and other metrics, an optimisation criterion can be introduced to take the demands of an application into account. The criterion can be a simple variable, set to a specific value that represents a demand of the application towards the node to base station communication system. Via this criterion, the  
10 application can signal the link layer the desired quality of service parameters and the link layer can adjust the communication device based on this knowledge to best suited mode of operation – considering correlations and past statistics of the environmental influences on the performance of the communication device.

[0036] From an implementation perspective, the system is as illustrated 30 in Fig. 2, and consists  
15 of four core components to optimize the communication device towards an application specific optimisation criterion.

[0037] 1. A statistical model 31 that captures statistics of past and current channel conditions or network parameters over various metrics on the different communication devices, antennas, data-rates, modulation settings, including but not limited to: n-n link quality, packet  
20 reception rate, bit error rate, detected receive energy, transmit energy, CRC errors, detected channel noise strength, number of neighbours, application data-rate, number of neighbour nodes, hops to the base station. Most of the parameters can be gathered over time by regular communications or by employing low energy beaconing mechanisms (duty cycling of the radio) – which is a standard technique in wireless sensor networks. The model also contains statistics of  
25 the sensor values obtained in the past and now.

[0038] 2. A model 32 containing fixed parameters of the sensor node, the used communication medium and it's environment, including but not limited to: Energy required per bit for transmitter n, approximate path loss coefficient for this environment, climate zone / GPS coordinate for this node, transmit power steps available for transmitter n, modulation settings  
30 available for transmitter n, data-rate settings available for transmitter n, time frames to perform a specific operation on transmitter n, mobility parameters (in case of mobile sensing devices).

[0039] 3. A correlator 33 to derive correlations of sensor obtained phenomena data with the captured statistics or current values of the statistical model. These derived correlations can detect real correlations of sensor measurements with the obtained channel conditions at the moment or in  
35 the past. A valid correlation in a forest like environment could for example be: "If the wind speed

- 7 -

is higher than 20 km/h, packet loss on the link to neighbour XYZ may occur.” The natural cause for this being multipath; such a correlation can then be used by the optimizer to tune communication parameters. Another example could be: “Selecting antenna X improves the link to neighbour XYZ in cases where the temperature and humidity are high”. Complex nested correlations may be provided ahead of time via system input for example – but could also be derived based on computational resources and energy constraints.

[0040] 4. An optimizer 34, considers the gathered statistics, the fixed parameter model, the application demanded optimisation criterion and all correlations or predicted correlations at a certain point in time to derive the best communication method at this point in time or for the future. The derived method is then applied to the communication device (and the involved neighbours via standard methods of arranging agreements within the network). Predictions can be applied wherever possible.

[0041] It can therefore be seen that the arrangement 30 provides for a wireless network of nodes that can adapt their mode of communication based on: local environmental parameters measured by sensors connected to or integrated with the nodes; time of day; time of year; and prior environmental modelling; in order to optimise network performance. Performance measures include, but are not limited to: power usage, data rates, packet loss, packet delay, packet delay jitter, network reliability, network connectivity and network lifetime.

[0042] The following example illustrates the system in operation within a network of multiple nodes, connected to the base station via multihop links. The following assumptions are made.

[0043] -All nodes within the network send beacons on their default communication medium to evaluate neighbours and channel conditions. All nodes gather sensor data and transmit it in a multi-hop approach to the base station.

[0044] -Several nodes measure higher humidity levels within a sub-area of the network. Past measurements and beaconing and transmission results have shown a correlation between high humidity and packet loss in this area following a drop in temperature. (The correlator is aware of this correlation)

[0045] -The nodes in this sub network agree via a simple management protocol to change to a different modulation / frequency / antenna that has been shown (or is known) to work better in these conditions. Due to the diversity aspect of the hardware, the rest of the network remains unchanged – operating at its best condition.

[0046] Another example shows the versatility in data rates:

[0047] -A camera network operates in a default state (network statistics are evaluated continuously and known as in the prior example).

- 8 -

[0048] -A camera detects an alert and starts streaming of the video data to the base station.

[0049] -The optimizer of the nodes along the multi hop path detects this specific application demand of higher data rates and evaluates the communication media for their current quality and the possible best highest data rate suited. Utilising power amplifiers may also be considered, balancing the importance of the alarm with the energy demand of such operations.

[0050] -The path towards the base station agrees on a higher data rate link setting and optionally enables power amplifiers to bridge the now shorter communication distances.

To cover accumulated demand at a node, one to many communication links may be enabled at the same time to cover the intermediate application need.

[0051] Fig. 3 shows some flow charts illustrating the system further.

#### [0052] Implementation

[0053] In practice, the preferred embodiments can be implemented by suitable programming of the microcontroller unit 15 of each sensor node of Fig. 1. Multiple sensors can be attached to allow for further correlations.

[0054] The following example illustrates the operation when implemented with matrices on the node.

[0055] The statistical model gathers the wind speed of the environment over a period of 1 week. Within this one week, radio transmissions have taken place over the different radio frequency bands, with different modulation schemes and with different antennas. The default transmission is taking place in a round robin fashion (for example) or based on preloaded offline models that fit the optimal settings for the existing QoS requirements (such as ITU propagation recommendations). These models of the correlator and optimiser are then be adapted during the deployment as each node learns the specific conditions that govern the new deployment environment.

[0056] The transmissions result into a matrix consisting of the physical layer configuration (a tuple consisting of all variable parameters like {time, frequency band, frequency channel, modulation, data-rate, antenna} associated with a packet loss rate, energy consumption, application requirement fulfillment in percent etc. The value of application fulfillment can be easily received from the application via a defined quality of service contract with different percentages of fulfilment possible. An example Matrix for a single frequency band is illustrated below, where the full matrix would contain all gathered values:

- 9 -

[0057] { Time t1, ISM band 2.4GHz, Channel 12, FSK modulation, 250kbps, Antenna 1 } -> {3% packet loss, 1Joule, 100%}

[0058] { Time t2, ISM band 2.4GHz, Channel 12, FSK modulation, 250kbps, Antenna 1 } -> {2% packet loss, 1Joule, 100%}

5 [0059] { Time t3, ISM band 2.4GHz, Channel 12, FSK modulation, 250kbps, Antenna 1 } -> {1% packet loss, 1Joule, 100%}

[0060] { Time t4, ISM band 2.4GHz, Channel 12, FSK modulation, 250kbps, Antenna 1 } -> {0% packet loss, 1Joule, 100%}

10 [0061] { Time t5, ISM band 2.4GHz, Channel 12, FSK modulation, 250kbps, Antenna 1 } -> {0% packet loss, 1Joule, 100%}

[0062] { Time t6, ISM band 2.4GHz, Channel 12, FSK modulation, 250kbps, Antenna 1 } -> {1% packet loss, 1Joule, 100%}

[0063] Etc

15 [0064] Based on a measurement log of wind speed, illustrated in the matrix below, correlations can be derived by the correlator.

[0065] { Time t1 } -> {Wind speed 30km/h}

[0066] { Time t2 } -> {Wind speed 20km/h}

[0067] { Time t3 } -> {Wind speed 10km/h}

[0068] { Time t4 } -> {Wind speed 0km/h}

20 [0069] { Time t5 } -> {Wind speed 0km/h}

[0070] { Time t6 } -> {Wind speed 0km/h}

[0071] ...

25 [0072] The correlator identifies an almost linear correlation between % packet loss and wind speed via for example a curve fitting or linear equations. Thus the following example equation is stored in the correlator:

[0073] {ISM band 2.4GHz, Channel 12, FSK modulation, 250kbps, Antenna 1 } -> {packet loss = wind speed / 10 + x} (where x is the statistical error)

30 [0074] The correlations can be removed in cases where the equations are drastically violated (in the above example this would happen if the variation of x is above a defined threshold). The linear relation is an example only, the relation in itself may also be more complex.

[0075] If there is a request of the application layer for a highly reliable communication link (defined as >98%), the optimiser can take this correlation into account. In case the windspeed at this moment is very high, the optimiser may decide to delay the rely of the

- 10 -

transmission to a moment where the wind speed dropped to an acceptable value that may indicate better reliability.

[0076] However, in cases this is unacceptable from an application requirement, in cases where a second requirement would be a delivery time of 10 seconds for example, the optimiser may consider a change of a radio transmission parameter. This could be the case if the transmission on a different frequency band (say 900MHz) did not correlate to high packet loss for example. Thus the transmission may be attempted on 900MHz instead of 2.4GHz.

[0077] It is possible to distinguish between two basic cases of radio transmission parameters:

[0078] (1) Parameters that require no coordination between sensor nodes to achieve successful radio packet delivery. Examples are transmissions in different bands (eg., 900MHz vs 2.4GHz), or transmissions on different antennas. For high reliability of communication, simultaneous transmissions in multiple radio bands may be considered;

[0079] (2) Parameters that require coordination between sensor nodes, such as transmissions with different physical modes, on different channels, and receptions on different antennas. Changing these parameters may bare a significant cost in terms of time or resources (for example, requiring an accurate global time synchronization of nodes, or a bootstrapping mechanism to discover and coordinate physical modulation and channels of sensor nodes). These additional costs can be factored in the optimization variables of the correlator and optimizer.

[0080] To incorporate multiple environmental variables in the optimisation decision, the optimiser can base its configuration decision on: (1) offline developed models based on previous measurements in the deployment region that map the environmental conditions to quality of service metrics, including energy, link quality, delay; (2) supervised learning of the mapping between the environmental conditions and the QoS metrics that drive diversity decisions, with human operator input in the learning process; (3) unsupervised learning, where the model is learned locally by the nodes based on radio performance so far in various environmental conditions.

[0081] In all three cases, the environmental variables serve as independent variables and the radio performance metrics as dependent variables. The 3 models listed can map the dependent variables to the independent variables based on a learning method. An example of a learning method that could run in a distributed fashion is the implementation of multiple linear regression in sensor networks, as described in "Model-Based Monitoring for Early Warning Flood Detection" Elizabeth Basha (Massachusetts Institute of Technology, US); Sai Ravela (Massachusetts Institute of Technology, US); Daniela Rus (MIT, US), Sensys 2008, where the

nodes share their own independent variables to create a global prediction of dependent variables. Using a similar methodology, sensor nodes can share their sensor data from environmental sensors to establish a global view of environmental conditions, which then drives the radio configuration parameters (frequency band, antenna, modulation). This would entail sharing of the matrix columns described above for combination either at a central point, a cluster head node, or at each node with in a neighborhood.

#### Further examples

[0082] 1) A measurement node is deployed in a tidal influenced area. In this example, the node is deployed in a tidal zone so that it may be submerged at times. It has a depth sensor attached and has two different antennas, A1 optimized for RF underwater communication, A2 for over the air RF communication. As long timeframe correlations indicate that A1 is better for communication whenever the depth indicator shows a submerged status, this correlation is stored in a way like “if depth > 0, A1 = good link”. A possible second correlation stored is that “A2 is good when depth is <=0”. Based on these correlations, the node can automatically adjust to the proper antenna based on it’s environment (depth only in this case) and choose the best communication link based on the measured sensor data autonomously ahead of transmission to communicate with the network. Further correlations derived over long term timeframes may be time based, such as “from now, for 3 hours A1 will allow good communication, then for 6 hours A2 will allow good communication, then ...”.

[0083] 2) A sensor network deployed in the rainforest, with an application that demands a packet delivery of measurement data within one day. The nodes measure humidity and temperature in a large scale area. Over the course of multiple months, the temperature has affected all links in a way that high temperature (>25 degree) yielded to bad link quality (<10% end to end delivery). Due to the sensed temperature in second intervals, the node creates a correlation of “Time of the day” to “Temperature”. The correlation can look like: “if time of the day is between 8pm and 5am, temperature is <20 degrees” and may be implemented with hidden markov models to represent environmental phenomena states for example. As the further correlation (temperature > 25 degree = bad links) allows for a simple reasoning of the node, the node is aware that link quality is beneficial for end to end delivery during the time of 8pm to 5am. Considering the application demand of a possible one-day delay of packets, the node may hold back any data packets during the day and never consider sending a packet during the unbeneficial timeframe and thus save energy.

[0084] The preferred embodiment has the added advantage that it can reduce the energy consumption of almost any single or multiple antenna device, including but not limited to: Phones

- 12 -

and handheld devices, Wireless enabled CCTV systems, High data-rate streaming devices such as home multimedia systems or airplane systems.

[0085] In cases the sensors can provide altitude and tilt information of the antennas, radiation patterns (and resulting antenna types) may be suggested by the node to an end user interface. This information can be easily derived in cases where the tilt of the existing antennas varies over time and the resulting link qualities are used to derive the antenna propagation area of good reception within the tilt area. Thus a different antenna type with a wider or more narrow area may be suggested by the optimizer to further increase communication qualities (to the end user).

[0086] In cases where the system comprises of visual sensors such as a camera, obstacles may be detected dynamically and their influence to the communication link can be determined over time.

[0087] In other arrangements, a small delay circuit for N-1 antennas for one or more specific transmitters may be added to the hardware in order to achieve simple beam forming. Based on the optimisation criterion, the beam may be formed in a way so that interference with other nodes in the network is avoided – based on the current sensed environment and the correlations derived. In some embodiments, the beam forming is done with an antenna pair that has shown to be effective for more than one neighbour and the current environmental condition (see Fig. 4).

[0088] In some embodiments, beam forming is used in a multi-hop network to transmit to a number of neighbours on a first radio. Further, a different beam direction is used on a second radio to cover another set of nodes, equal to, overlapping with or completely different to the first set of neighbours covered by the first beam (see Fig. 4).

[0089] In some embodiments, the use of beam forming on any node to achieve the delivery to the next hop and at the same time achieve the delivery of the packet to the originating node (which is able to derive this as an acknowledgement). Thus, the delivery of separate acknowledgements to the source node is not necessary (see Fig. 6).

[0090] In some embodiments, whenever the time of the optimisation is not permanent, the node in demand may estimate the overhead to achieve the optimisation and decide to not optimize.

[0091] In some embodiments, other nodes may decrease their influences to the path during that time the optimisation criterion is active whenever the time of the optimisation is not permanent (see Fig. 5).

### **Interpretation**

[0092] 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 of the present invention. Thus, 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, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments.

[0093] Similarly it should be appreciated that in the above description of exemplary  
5 embodiments of the invention, various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following  
10 claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the Detailed Description are hereby expressly incorporated into this Detailed Description, with each claim standing on its own as a separate embodiment of this invention.

[0094] Furthermore, while some embodiments described herein include some but not other  
15 features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

[0095] Furthermore, some of the embodiments are described herein as a method or combination  
20 of elements of a method that can be implemented by a processor of a computer system or by other means of carrying out the function. Thus, a processor with the necessary instructions for carrying out such a method or element of a method forms a means for carrying out the method or element of a method. Furthermore, an element described herein of an apparatus embodiment is an example of a means for carrying out the function performed by the element for the purpose of carrying out  
25 the invention.

[0096] In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the invention may be practiced without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding of this description.

[0097] As used herein, unless otherwise specified the use of the ordinal adjectives "first", "second", "third", etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

[0098] In the claims below and the description herein, any one of the terms comprising,  
35 comprised of or which comprises is an open term that means including at least the

- 14 -

elements/features that follow, but not excluding others. Thus, the term comprising, when used in the claims, should not be interpreted as being limitative to the means or elements or steps listed thereafter. For example, the scope of the expression a device comprising A and B should not be limited to devices consisting only of elements A and B. Any one of the terms including or which includes or that includes as used herein is also an open term that also means including at least the elements/features that follow the term, but not excluding others. Thus, including is synonymous with and means comprising.

[0099] Similarly, it is to be noticed that the term coupled, when used in the claims, should not be interpreted as being limitative to direct connections only. The terms "coupled" and "connected," along with their derivatives, may be used. It should be understood that these terms are not intended as synonyms for each other. Thus, the scope of the expression a device A coupled to a device B should not be limited to devices or systems wherein an output of device A is directly connected to an input of device B. It means that there exists a path between an output of A and an input of B which may be a path including other devices or means. "Coupled" may mean that two or more elements are either in direct physical or electrical contact, or that two or more elements are not in direct contact with each other but yet still co-operate or interact with each other.

[00100] Although the present invention has been described with particular reference to certain preferred embodiments thereof, variations and modifications of the present invention can be effected within the spirit and scope of the following claims.

- 15 -

We Claim:

1. A node in a wireless network, said node including:  
a radio frequency transmission unit for transmitting data as part of the wireless network;  
at least one sensor attached to the node for sensing the local environmental parameters  
5 surrounding said node;  
processing unit for optimizing the mode of communication by said radio frequency  
transmission unit based on the influence of the measured local environmental parameters.
2. A node as claimed in claim 1 wherein said optimizing includes taking into account at least  
10 one of time of day, time of year and prior environmental modelling; in order to optimize network  
performance.
3. A node as claimed in any previous claim wherein the performance measures utilized in  
said optimizing include at least one of: power usage, data rates, packet loss, packet delay, packet  
15 delay jitter, network reliability, network connectivity and network lifetime.
4. A node as claimed in any previous claim wherein the local environmental parameters  
include at least one of: temperature, wind speed, wind direction, wind rotation, pressure, ambient  
light, humidity, flooding, vibration, impact, seismic activity, smoke, rain fall, rain rate or any  
20 gradients thereof.
5. A node as claimed in any previous claim wherein said optimizing includes measuring the  
local environmental parameters, updating a functional estimate of the relationship between these  
parameters and the optimal mode of communication, and selecting the mode of communication by  
25 using the measured parameters and the functional relationship.
6. A node as claimed in any previous claim wherein said optimizing includes optimisation of  
at least one of: a multiplicity of transducer elements, a multiplicity of frequency bands, a  
multiplicity of possible operating frequencies within the frequency bands, a multiplicity of  
30 modulation waveforms, a multiplicity of coding methods or a multiplicity of network routes.
7. A node as claimed in any previous claim wherein the sensor includes an infrared, acoustic  
or other communication device.

- 16 -

8. A node as claimed in any previous claim wherein said wireless network includes nodes having no sensors.

9. A node as claimed in any previous claim wherein optimization information is distributed to other nodes in said network.

10. A node as claimed in any previous claim wherein link failures are made known to the whole network to allow other nodes the evaluation of recovery strategies.

11. A node as claimed in any previous claim wherein any derived significant statistical data is distributed within the network to allow any node to utilize the data in determining an optimization of that node.

12. A node as claimed in any previous claim wherein said radio frequency transmission unit includes a series of omnidirectional or directional radiation antenna and said optimizing includes optimizing the directional characteristics of said radiation.

13. A node as claimed in any previous claim wherein said sensor includes line of sight sensor and said optimization includes dynamically determining the line of sight characteristics between nodes.

14. A node as claimed in claim 12 wherein said optimizing includes beam forming of the radiation pattern.

15. A node as claimed in claim 14 wherein said optimizing includes beam forming to avoid interference between nodes.

16. A node as claimed in any previous claim wherein a node experiences intermittent transmission requirements and increases its priority during active transmissions.

17. A node as claimed in any previous claim wherein one of said optimization criteria is the power requirements incurred during the optimization process.

18. A node as claimed in claim 14 wherein said beamforming is done to allow transmission to more than one neighboring node.

- 17 -

19. A node as claimed in claim 18 wherein said network includes multi-hops and said radio frequency transmission unit includes a series of directional radiation antenna divided into at least two sets, with a first set having first optimized beam characteristics and a second set having  
5 second optimized beam characteristics with the two beam directions covering a set of nodes in the network which are either equal to, overlapping or completely different to each set.

20. A node as claimed in claim 18 wherein said network includes multi-hops and a first transmission occurs to a next hop and simultaneously to an originating node.

10

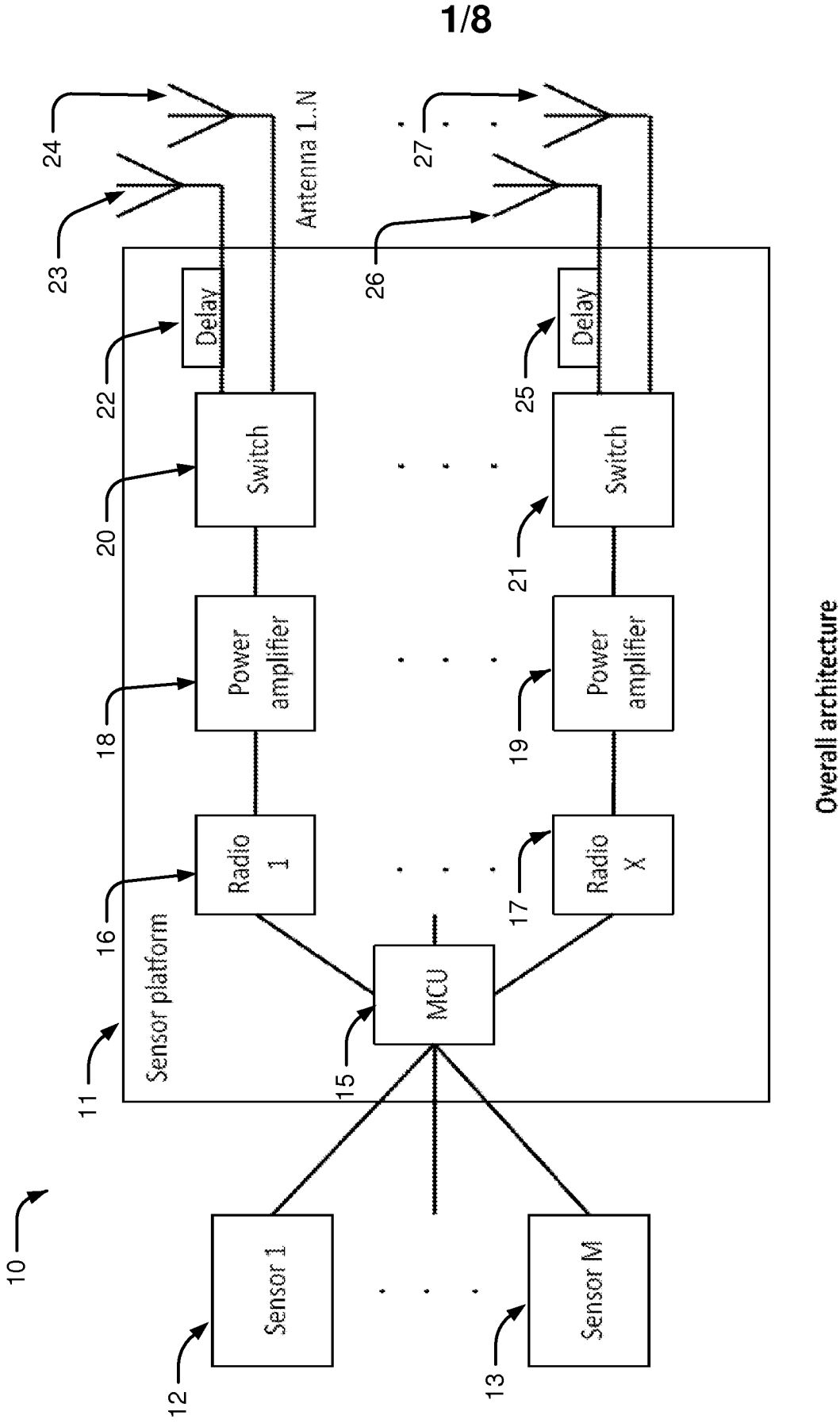


Fig. 1

2/8

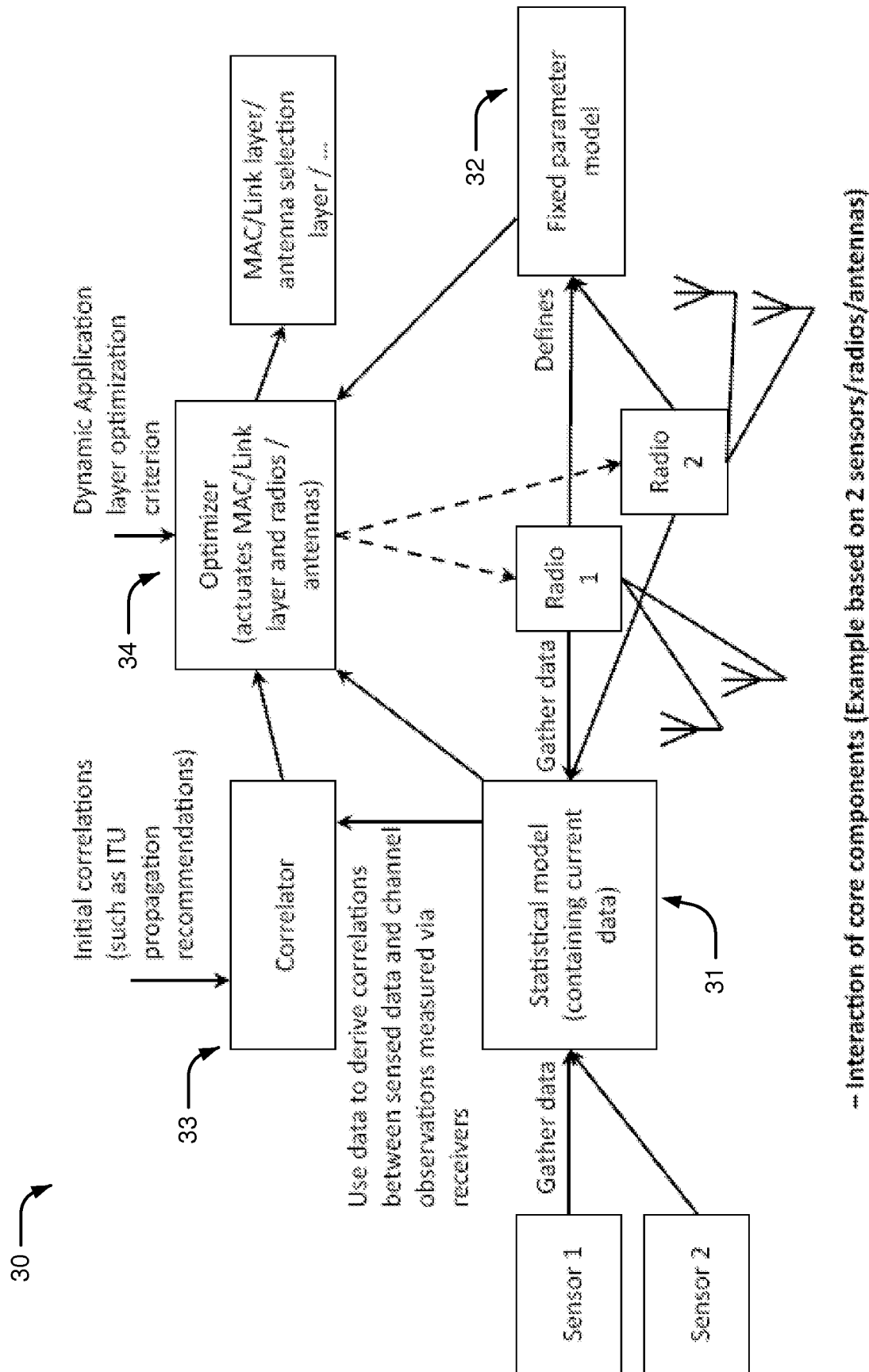
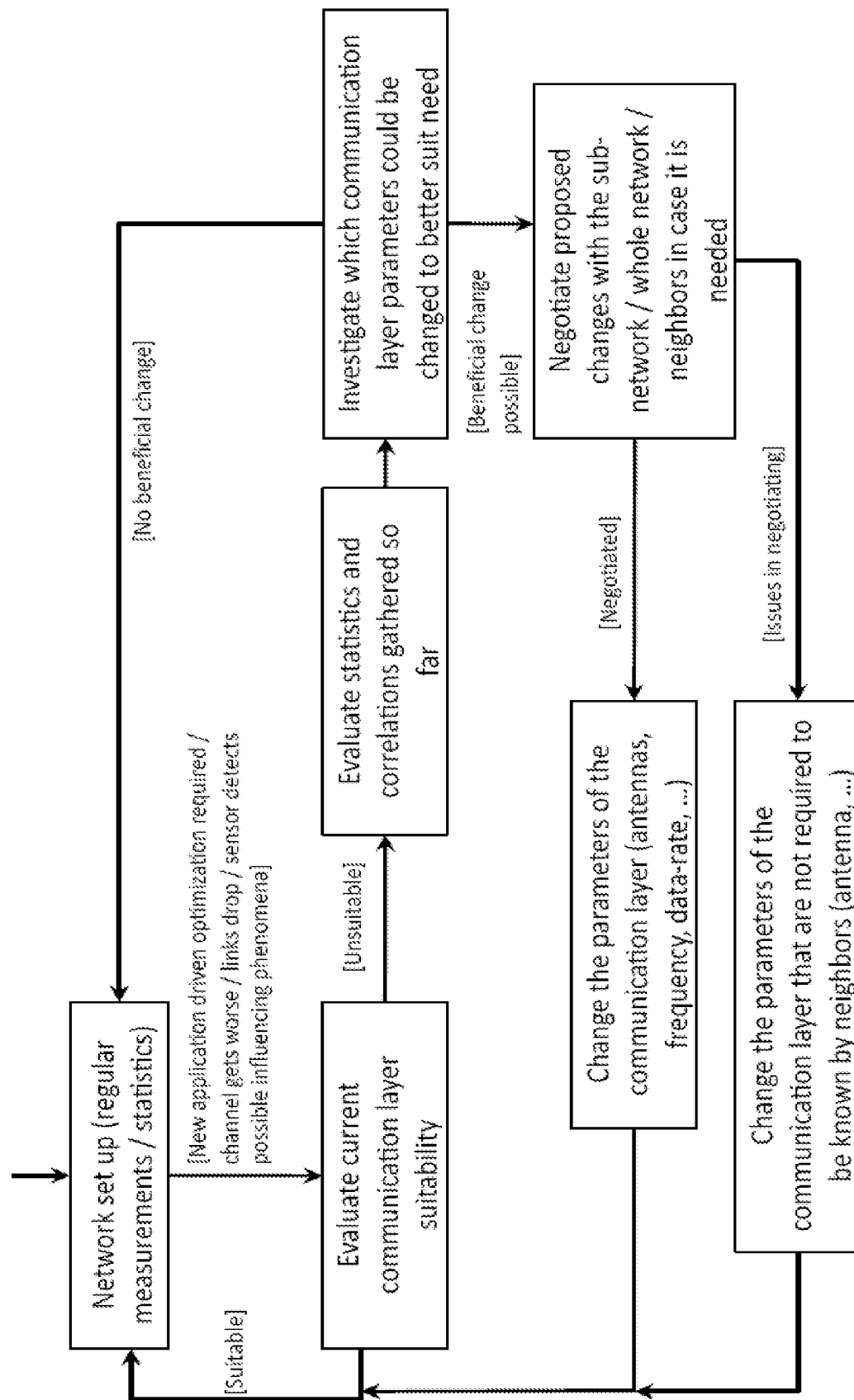


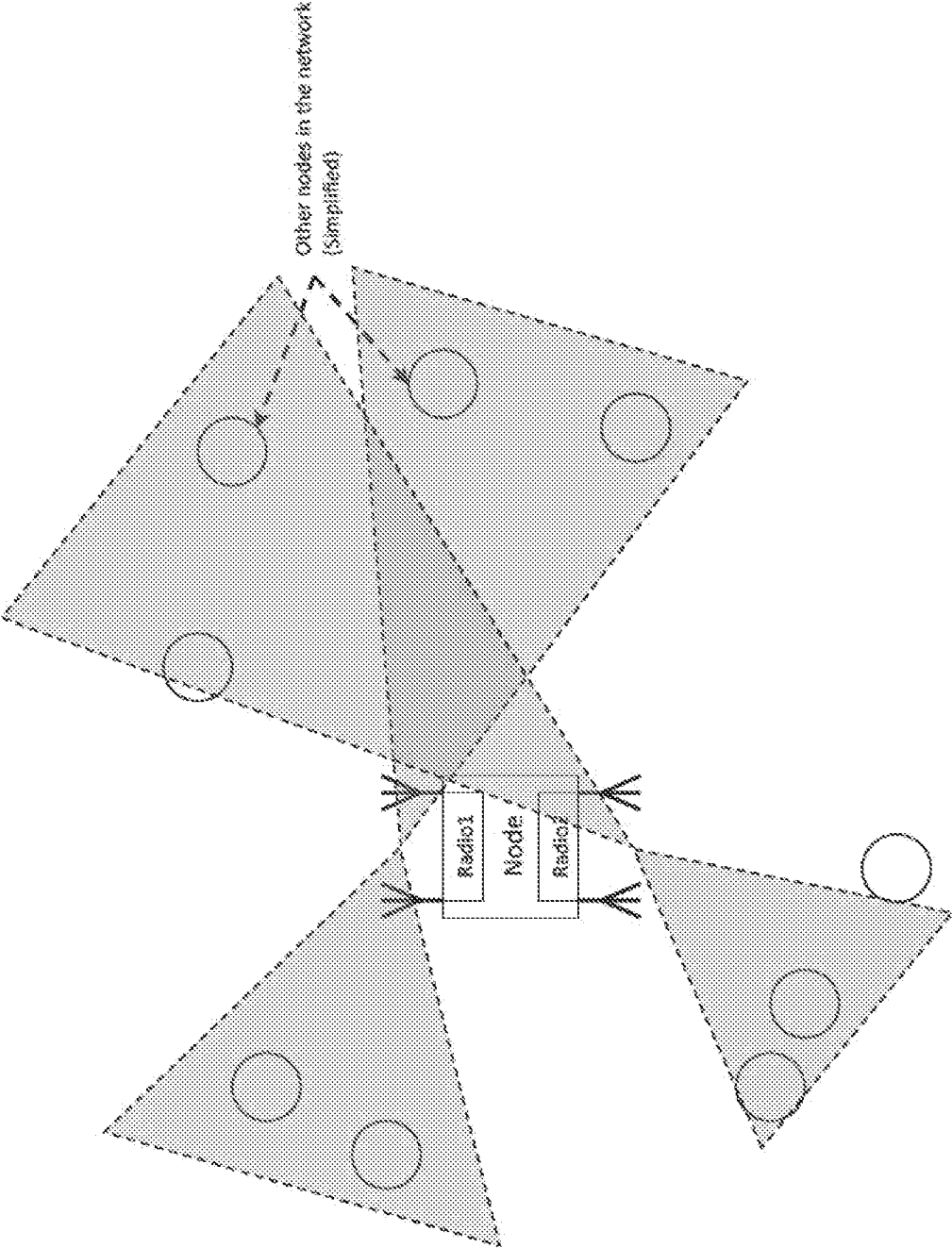
FIG. 2

3/8



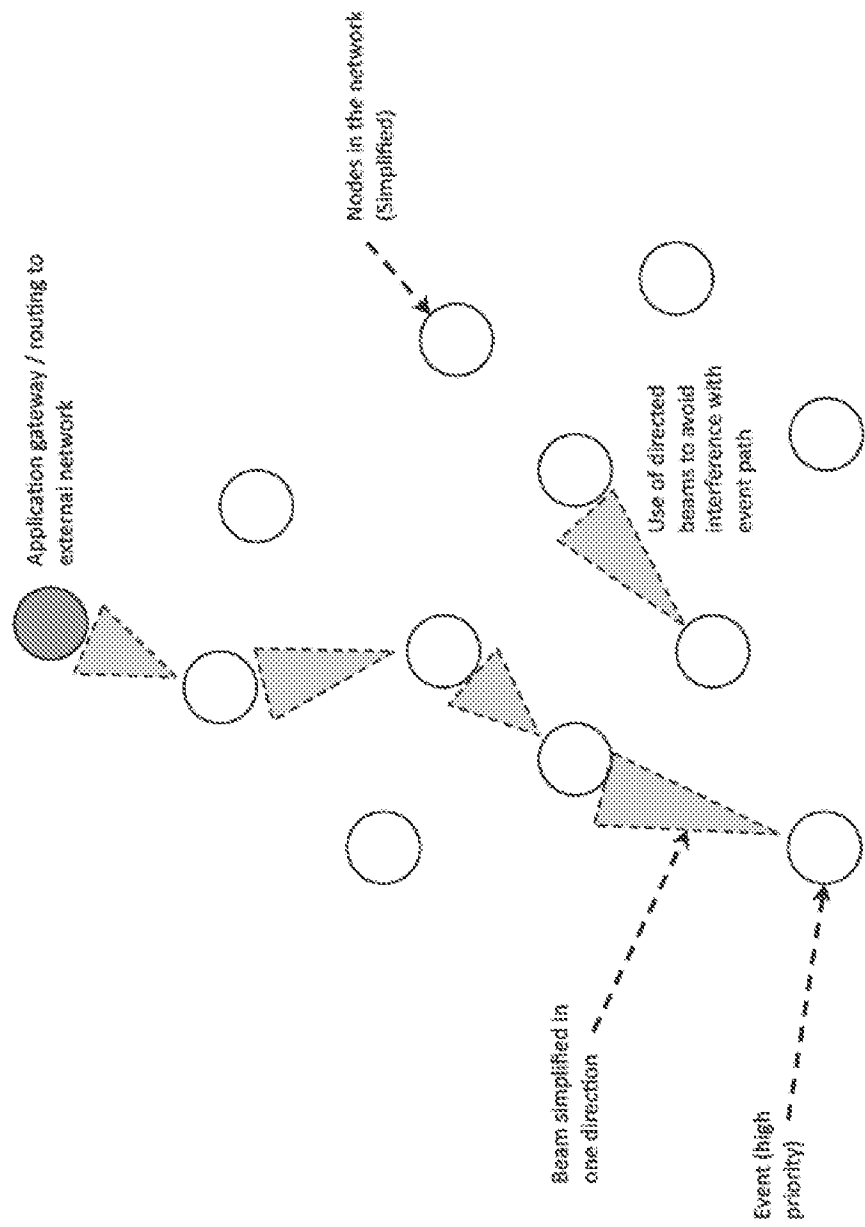
- Flow chart of example operation

**FIG. 3**



~ Use of beam forming on different frequencies to cover different network areas more effective  
(possible at the same time)

FIG. 4



...Use of beam to effectively mitigate interference on important optimizations

FIG. 5

6/8

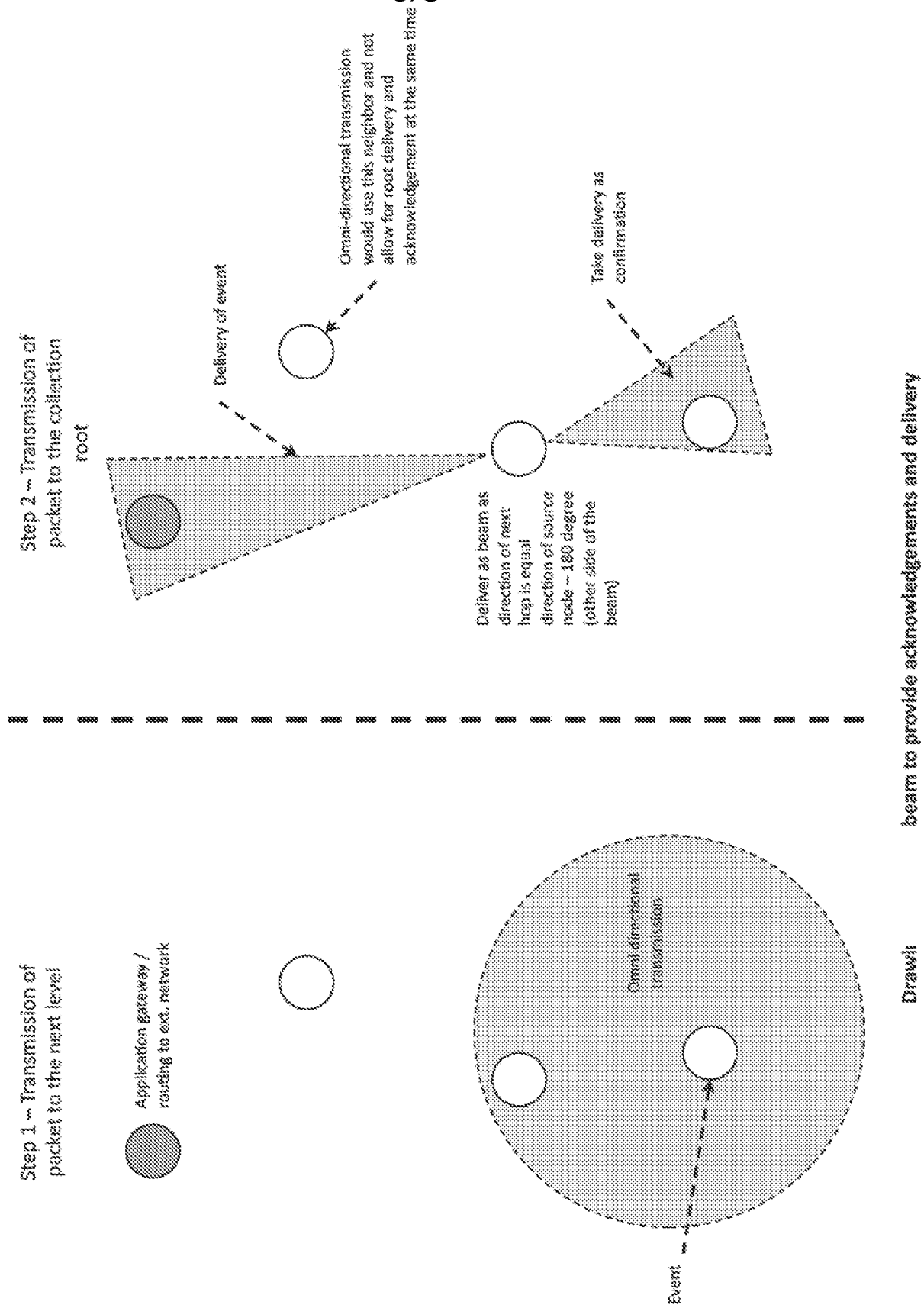


Fig. 6

7/8

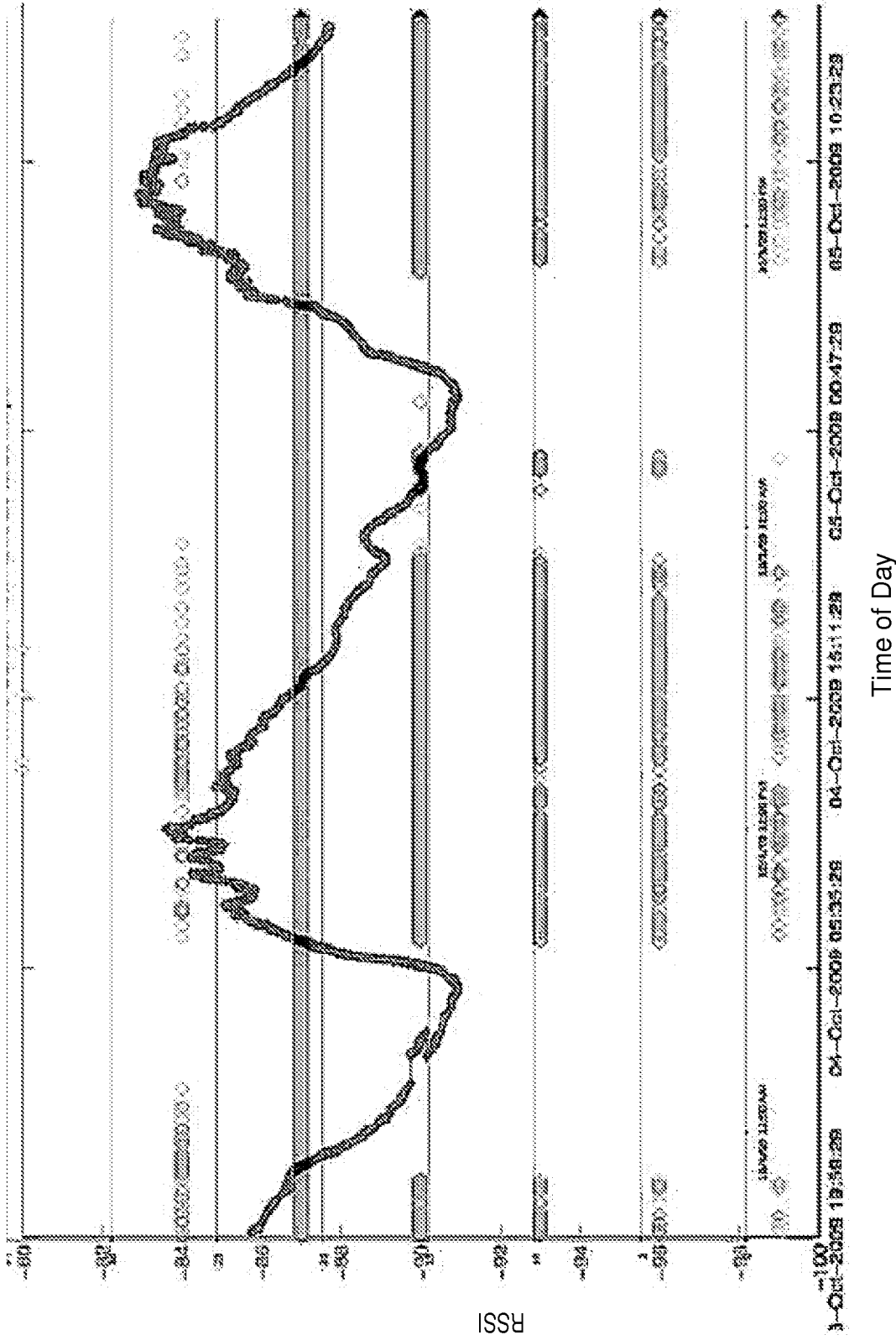
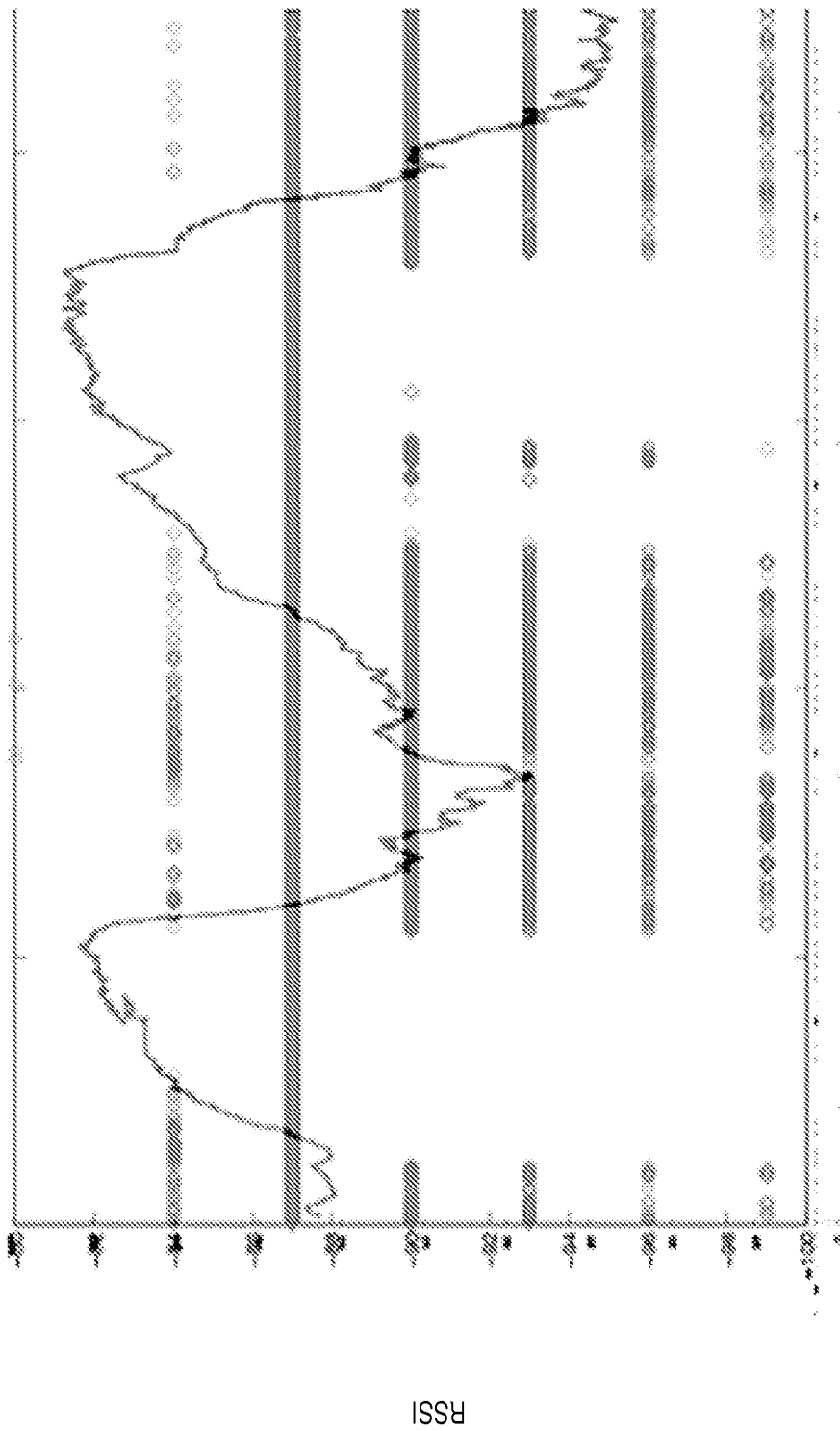


Fig. 7



Time of Day

FIG. 8

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2011/000397

## A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H04W 72/00 (2009.01)

H04W 24/02 (2009.01)

H04B 7/00 (2006.01)

H04W 88/02 (2009.01)

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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

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

EPODOC, WPI (abstracts); GOOGLE keywords: WIRELESS, RADIO, TRANSMITTER, SENSOR, ENVIRONMENTAL, CHANNEL, COMMUNICATION MODE and other terms and phrases.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 2008/0143518 A1(AARON) 19 June 2008<br>Abstract, paragraphs [0002], [0004], [0005], [0011]-[0013], [0016], [0019], [0022], [0026], [0030], Figs.1-3<br><br>KOWALSKI, R.: "THE BENEFITS OF DYNAMIC ADAPTIVE MODULATION FOR HIGH CAPACITY WIRELESS BACKHAUL SOLUTIONS", Ceragon Networks, White Paper, October 2007, p.1-6.<br>Retrieved from the Internet on 14 June 2011 at:<br><a href="http://www.ceragon.com/files/The%20Benefits%20of%20Dynamic%20Adaptive%20Modulation.pdf">http://www.ceragon.com/files/The%20Benefits%20of%20Dynamic%20Adaptive%20Modulation.pdf</a> | 1-20                  |
| Y         | Whole document, Fig. 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 1-20                  |



Further documents are listed in the continuation of Box C



See patent family annex

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"E" earlier application or patent but published on or after the international filing date

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"Q" document referring to an oral disclosure, use, exhibition or other means

"&amp;" document member of the same patent family

"P" document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search  
14 June 2011Date of mailing of the international search report  
17 JUN 2011Name and mailing address of the ISA/AU  
AUSTRALIAN PATENT OFFICE  
PO BOX 200, WODEN ACT 2606, AUSTRALIA  
E-mail address: pct@ipaustralia.gov.au  
Facsimile No. +61 2 6283 7999Authorized officer  
**BAYER MITROVIC**  
AUSTRALIAN PATENT OFFICE  
(ISO 9001 Quality Certified Service)  
Telephone No : +61 2 6283 2164

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/AU2011/000397**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

| Patent Document Cited in<br>Search Report                                                                                 |            | Patent Family Member |         |    |            |
|---------------------------------------------------------------------------------------------------------------------------|------------|----------------------|---------|----|------------|
| US                                                                                                                        | 2008143518 | US                   | 7646297 | US | 2010066546 |
| Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001. |            |                      |         |    |            |
| END OF ANNEX                                                                                                              |            |                      |         |    |            |