How to improve the Performance of a Mesh Wireless Sensor Network?

Overview - Wireless Sensor Networks and their Performance

The main goal of a wireless sensor network is to enable the reception of data from the sensor field without the need for physical connection or access. An additional possible goal is the remote control of the sensors by the sensor application.

In a classic example of an electrical metering application, wireless sensor networks can be used to build an Advanced Metering Infrastructure (AMI) which can continuously monitor the power consumption, and control the functionality of the meters, as well as limit the end-user consumption or report about tampering with the meters in real-time.

Such capabilities are important for enabling the electric utilities to reduce operational expenses, implement flexible management systems based on real-time energy consumption monitoring, increase the system's reliability and ultimately help to reduce cost and save energy.

Mesh topology has proved to offer the best choice for a large range of wireless sensor network applications. Furthermore, often mesh is the only feasible topology for modern projects. The critical factors influencing the *performance* of a wireless mesh network vary from application to application, and applications usually require most of the following capabilities:

– Range and coverage: these are probably the most obvious requirements for a wireless network, starting from the node to node range at a given transmission power / antenna gain and data rate. Range is affected by the quality of the physical layer and the efficiency of transmitting the data through the network. In mesh topology, the technology also necessitates subtler and often more important range related points, such as the influence of multi-path conditions and changes, or how the requirements are affected when the nodes operate in mesh topology rather than just between two separate nodes. Closely related to range, are the coverage requirements, which are mainly the elimination of dead spots in the network and the extent of the coverage area in multiples of the basic node-to-node range.
– Robustness to changes and RF interferences: some changes can be internal, such as adding or removing nodes, or changes in the location of nodes. Others are external, influencing the propagation path, such as the addition (or removal) of walls or buildings or more trivial, like the replacement of a door in the RF path by a metallic one. Again, subtle, but important related points are about how the network *reacts* to changes, for example: could the network go down because of the changes, and if so for how long, or how long would it take for the network to recognize the new conditions or configuration, as some applications are sensitive to such timing.
– Scalability: the ability to cope with network cells as small as a few nodes to cells of thousands or even tens of thousands of nodes, including the ability to increase the size of the existing network by orders of magnitude. Another aspect is the *spatial* scalability, with cells as small as a few meters to cells as large as few kilometres without the necessity to employ expensive cellular communication or other long-range solutions.
– Power consumption: for some applications, a vital factor is the longest period of time that a node can operate on a battery. In other applications, the key

performance is the ability to mix between nodes with various power supply types and capacity.

- Ease of integration, use and maintenance: in mesh applications such ease is an absolute critical factor. For example, in some organizations the need to train the deployment staff may preclude the move to wireless; in others, the network management resources reduce or even annul the operational cost benefits of the network. An opposite example is of networks that enable an immediate move from wire to wireless, without any need for new management software or thorough modifications: for example, just by cutting the existing RS485 or MODBUS wires and inserting the network nodes

Reliability and data throughput are always important performance factors.

Despite the fact that mesh topology is often the best option for numerous applications, the vast majority of wireless network technologies today are configurable to all the relevant topologies, thus addressing their lowest common denominator. Such strategy can be justified only if the application requires several topologies to be applied concomitantly or at least in the same project.

However, when it is clear that the only topology is mesh, it only makes sense to use a technology targeted specifically to the mesh topology.

"Everything should be made as simple as possible, but not simpler"[1]

This white paper presents Diversity Path Mesh, a technology designed to maximize the most important performance factors of wireless mesh networks, as well as their trade-off envelope. Diversity Path Mesh™ is a multi-hop, bi-directional communication technology, developed for wireless sensor networks using mesh topology and operating in the unlicensed frequency ranges.

The basic technique employed in Diversity Path Mesh is known as *flooding*, where a node transmits the very same message to all the nodes in the network cell, in a flat hierarchy. The theoretical concept of flooding in networks as an alternative to routing is well known.

In a flooding-based network, all units receive the message data, thus eliminating the need to rout messages in the network - a most demanding network management task. Eliminating the routing also decreases the amount of data carried in the network, since messages contain only pure data, with no waste on routing information. In addition, flooding adds to the network a dimension of multiple propagation paths which improves the robustness tremendously. Furthermore, there is no set-up time and any number of nodes can be inserted or removed, and as long as the added or remaining nodes are within the reception range, the network simply continues to operate. There is no realigning time and no down-time of the network.

However, the use of flooding in standard mesh network architectures has been avoided for several reasons, the main one being the “broadcast storm problem”, where nodes within reception range retransmit the message approximately at the same time, with the resulting collisions increasing the energy consumption to unreasonable levels.

To channel the flooding technique into a practical and useful solution, Diversity Path Mesh complements it with a technique known as *simulcast*. Messages of each node are *relayed* by the surrounding nodes at controlled timing, thus forming

[1] Albert Einstein (1879 - 1955)

multiple transmission paths on the way to the destination. The retransmission of the messages through the network is *synchronised* to sub-bit level, with TDMA as the master construction framework. The multiple identical transmissions received by the node receivers are summed in the de-modulator, increasing the strength of the signal.

The results are increased reliability, as there is no single point (node) of failure; and increased propagation robustness, due to the inherent *spatial diversity* of the propagation through the various diverse channels of the multiple relay paths. This propagation robustness translates to greater range and also practically eliminates dead spots in all conditions - in steady state, when multipath occurs, when there is RF interference and when changes in the propagation conditions occur.

In other words, there is a significant reduction in the probability of a message to fail reaching its destination. As the propagation over many paths occurs simultaneously, the propagation time that would have been required if they would have been transmitted one after the other is reduced to a minimum. Relaying the messages also enables Diversity Path Mesh networks to extend as far as needed, with the cell overall range and robustness rising with the increase of the number of the nodes. The maximum number of nodes exceeds any practical requirement of such applications.

In a nutshell, the behaviour of a Diversity Path Mesh network based on these techniques is as following:

- The nodes are the network - there are no routers. Once the nodes are connected and powered, the network is up and running. Also there is no need for network management and consequently no need to develop software to manage the network. Compared to router based networks, several months of software development and field tests are eliminated.
- The operation of adding or removing nodes is immediate and effortless. There is no such notion as re-programming or re-setting, hence there are no corresponding delays and no down-time.
- Messages propagate in simultaneous, parallel paths, thus increasing the range between nodes and improving the resiliency to the ever changing conditions of obstructions and RF interferences.
- The network traffic contains practically only pure data with no management overhead, resulting in high data throughput and subsequent low power consumption.
- The maximum limit of times the data is retransmitted by relaying (the number of legs or hops) is practically unlimited, with actual numbers far exceeding the requirements of real-life applications. For example, with the basic range between nodes being some 2 kilometres with the high power module, a coverage area spanning 60 km can be easily achieved with 30 hops in a Diversity Path Mesh network cell.
- The maximum limit of nodes in a Diversity Path Mesh network cell also far exceeds the requirements of real applications. Increasing the number of nodes either increases the size of the network cell, or the robustness of the network, or both.

Conclusion

Designing and developing from scratch a wireless sensor network specifically for mesh topology, while learning from the drawbacks of the existing technologies, seems like the most suitable approach for achieving the highest set of performance. Flooding is arguably the most appropriate technique to be considered for this purpose, as it addresses the most critical performance factors of wireless mesh networks, as well as the overall factors' envelope. However, the flooding technique carries several grave drawbacks, which have until now precluded its use in this type of networks.

Diversity Path Mesh is probably the first mesh wireless network to use the flooding technique instead of routing, as it has managed to overcome any disadvantages of flooding by using the simulcast technique, which combines relaying and synchronization at sub-bit level, resulting in a surprisingly and revolutionary set of performances. At the same time, it encompasses all the benefits of the flooding technique.

Products based on this technology and deployed by its originator, Virtual Extension, have proven the Diversity Path Mesh capability, as they have been successfully deployed in numerous projects, where products based on other technologies either have failed or would have failed. These applications include Utility Automation – Electricity and Water, Building Automation, Industrial Automation, Vending Machines, Agriculture and Security.

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