COST/BENEFIT ANALYSYS OF THE W2LAN PROTOCOL

Francesc Burrull, Francisco Miguel Monzo-Sanchez,
Josemaria Malgosa-Sanahuja, Joan Garcia-Haro

Depart. of Information Technologies and Communications, Polytechnic University of Cartagena
Campus Muralla de Mar s/n, Cartagena, E-30202, Spain
Ph. +34 968 325365, Fax +34 968 325338
email: {francesc.burrull, francisco.monzo, josem.malgosa, joang.haro}@upct.es

ABSTRACT
The W2LAN (Wireless to LAN protocol) is a pure layer-2 protocol that transforms a MANET (Mobile Ad-Hoc Network) Ethernet network into a simple Ethernet network from the point of view of higher layers. The benefit of using W2LAN is that a set of N nodes will have total visibility, eliminating the inherent problem of partial visibility that MANET networks present. To evaluate the protocol, a SDL (Specification and Description Language) model with N nodes has been constructed, and a simulator instance automatically derived from it. The Cost/Benefit analysis consists of finding out the cost in number of frames being used by the W2LAN protocol in comparison with a conventional LAN under different set of parameters.

KEY WORDS
Mobile Ad Hoc Networks (MANETs), LAN, Broadcast Protocol Modelling and Simulation, Specification and Description Language (SDL).

1. Introduction

Since the W2LAN protocol is specified in [1], to better understand the paper a brief summary of its model is informally described here.

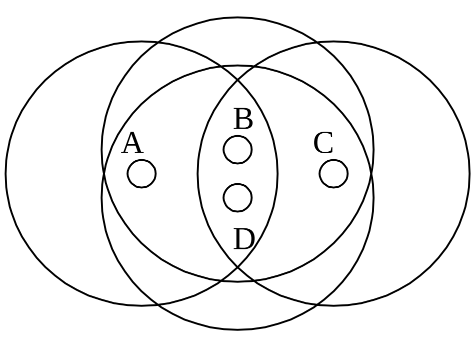

Figure 1: Example of an Ad-hoc network topology

If a node (Figure 1, A) wants to share a piece of information –information 'a'-, first of all it is announced, "Does somebody want information 'a'?" [Announce frame]. Nodes surrounding the source (B and D), if they are interested, they will answer with the request "Yes, I am interested in information 'a'" [Request frames]. Then, if the source gets any requests, it finishes the conversation [W2LAN transaction] by delivering information 'a' [Data frame]. The next iteration is performed by the surroundings of the source (B and D), since they have become sources. It should be noticed that the propagation of information 'a' [W2LAN conversation] is going to be spread to every node and disappear by lack of interest (nobody will answer C) in a known information.

The W2LAN protocol operates as a layer on top of an Ethernet device (between MAC and DLC layers). When a node decides to transmit a frame (from higher layers), instead of transmitting the frame directly, it is passed to the W2LAN layer, which it will start at this point a new W2LAN conversation C_N by issuing a W2LAN Announce frame [broadcast, containing the original Ethernet header plus a unique conversation ID]. Complementarily, when a surrounding node is interested in the announced C_N, its corresponding Data frame is requested with a Request frame. Eventually this node will receive the corresponding W2LAN Data frame [broadcast, containing the original Ethernet body plus the corresponding conversation ID], and its W2LAN layer will reconstruct and, if necessary, deliver the Ethernet frame associated to upper layers as a normal Ethernet device does. Finally, this node announces the newly received Ethernet frame by means of an Announce frame of C_N., iterating the process until the conversation C_N is extinguished by lack of interest of any node.

What is expected from the simulation is to find the cost in frames of using the W2LAN protocol under arbitrary situations. Another way to describe this cost is by using the concept of W2LAN conversation, which is a set of frames that share the same ID. In a pure Ethernet LAN, a conversation/communication would consist of only one frame –from the sender to the receiver(s)-, but in a W2LAN environment a conversation consists of a number of frames –announces, requests and data frames- that eventually disappear from the W2LAN network.

The cost of using W2LAN varies depending on three parameters: The number of nodes participating in the network, their coverage radius, and the node topology.

A priori the first parameter, number of nodes in the network, seems to have a direct proportion in the cost: The more nodes, the more frames. The second parameter, coverage radius of the nodes, is expected to have an inverse proportion in the cost: The more coverage, the less frame repetition. The third parameter, the node topology, adds uncertainty, since there is an infinite variety of topologies.

Most of the major MANET routing protocols, such AODV (Ad hoc on-demand distance vector [2]) and DSR (The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks [3]) operate at network layer (layer-3) and they use route information to perform packet forwarding. These protocols have to take into account node mobility carefully, sometimes applying mobility restrictions [4], since node mobility directly affects the overhead that associated to these protocols. On the contrary, W2LAN is a layer-2 protocol that forwards frames with no knowledge of routes or positions. When a generic node tries to send an Ethernet frame to another node, a W2LAN conversation is formed by a number of W2LAN transactions (some useful, some redundant) that flood the network. Within this flood, there is always a path that will deliver the Ethernet frame from origin to destination, and this will be the shortest one. Since each Ethernet frame is treated as independent, W2LAN does not have any record on routes, hence each W2LAN conversation always finds the shortest path -which may vary according to node mobility patterns- between communicating nodes. Therefore, the W2LAN simulations performed do not consider the mobility of the nodes.

The rest of the paper is organized as follows: Section 2 explains the simulation tool developed to evaluate the W2LAN protocol. Section 3 describes the scenarios being used to obtain simulation results. In section 4, the simulation results are discussed. In section 5 a graphical cost/benefit analysis is illustrated. Finally, section 6 explains scenarios where W2LAN has acceptable performance and concludes the paper.

2. Simulation Tool

The W2LAN protocol has been specified in SDL (Specification and Description Language [5]), a formal description language accepted as a standard by the ITU (International Telecommunications Union [6]), recommendation Z101-Z104. To perform an automatic validation of the protocol it has been modeled with the SDL-TTCN Suite from Telelogic [7], which also allows the automatic derivation of a simulator module.

The simulation model consists on a SDL system block with one instance of broadcast channel and *N* instances of nodes (launched by the channel process) executing the W2LAN protocol (figure 2). The frames have been modified to include the node positions for coverage calculation only.

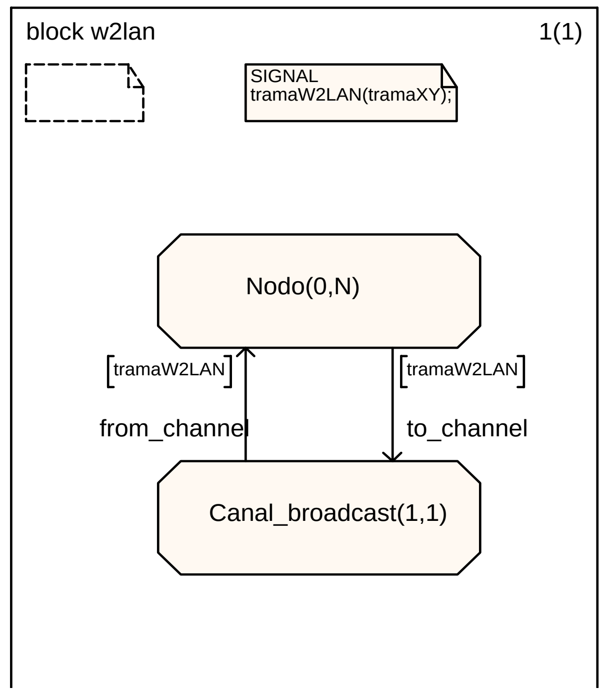

Figure 2: Block w2lan (1 channel, N nodes)

Once a simulator is obtained, it can be systematically executed with different input parameters by means of scripts, storing the simulation results in text files for further analysis.

3. Scenarios

A scenario consists of a normalized square of one unit side, where the nodes are being placed on. Then, the coverage radius of the nodes is expressed in relation to the side of the square. For the sake of simplicity, all nodes are considered to be equal. Consequently, a scenario can be described as a particular set of parameters: A number of nodes, the coverage radius of the nodes and the node topology.

In this paper three topologies are being studied: Linear grid, square grid and random grid. The selection has been done in order of complexity, to better understand the protocol behaviour, but the simulator is ready for any number of nodes, any coverage radius and any topology.

Also, these topologies have special interest because they can reflect typical use cases: The linear grid can be applied to create network perimeters (e.g. highways), the square grid can be used to give coverage to a certain area, and the random grid may represent mobility scenarios.

3.1 Linear grid

The linear grid is the simplest experiment being conducted. It consists of a series of nodes placed along the bottom horizontal side of the one-unit square. For example, the first experiment (Figure 3) consists of 2 nodes separated a distance of 1 unit. The trivial result obtained, for a coverage radius equal to 1, is that the cost of any conversation is 4. These conversations consist of 1 announce packet, 1 request packet, 1 data packet and 1 announce packet. It should be noticed that announce packets have always the size of 34 bytes and request packets have always the size of 20 bytes. The data packet has exactly the same size than the original Ethernet frame being carried by the conversation [1]. In general, a number of N nodes, $N \geq 2$, are placed along the bottom horizontal side of the one-unit square.

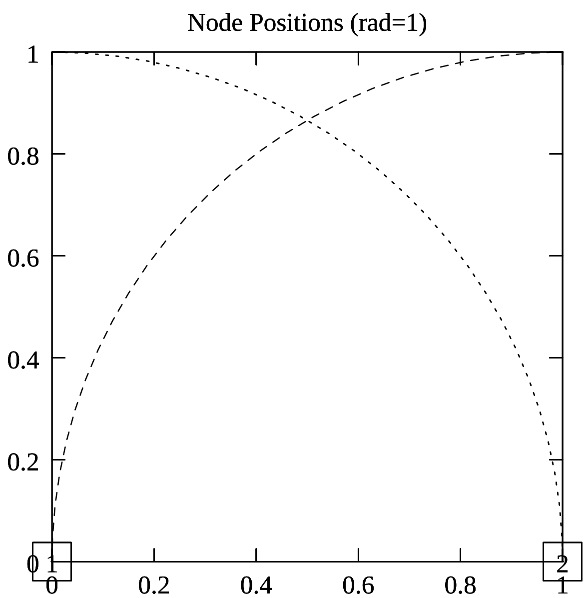

Figure 3: Linear grid. First experiment conducted

3.1 Square grid

The square grid is the natural extension of the linear grid in two dimensions. It consists of a series of nodes placed from the bottom-left corner of the one-unit square to its top-right corner, with equal horizontal and vertical distances between them. For example, the first experiment (Figure 4) consists of 4 nodes, one on each corner. The first result obtained, for a coverage radius equal to 1, is that the cost of any conversation is 9. These conversations consist of 1 announce packet, 2 request packets, 1 data packet, 2 announce packets, 1 request packet (to the first announcer), 1 data packet (from the first announcer) and 1 announce packet. The second result obtained, for a coverage radius equal to $\sqrt{2}$, is that the cost of any conversation is 8. These conversations consist of 1 announce packet, 3 request packets, 1 data packet, and 3 announce packet. Both results are better than the theoretical upper bound described in section 4. In general, a number of i^2 nodes, $i \geq 2$, are placed on the one-unit square as described above.

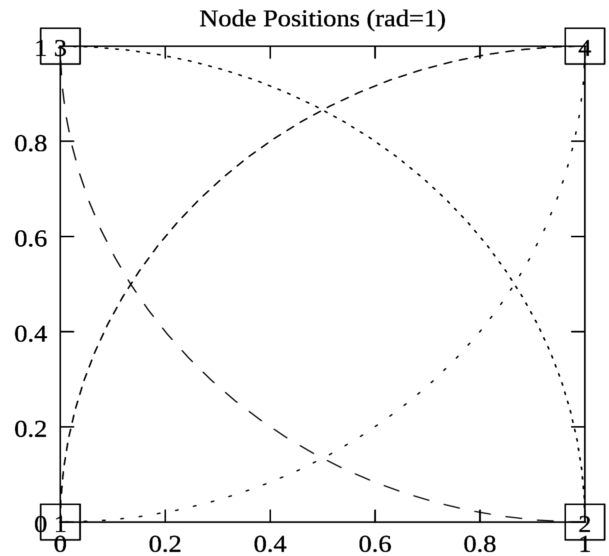

Figure 4: Square grid

3.1 Random grid

The number of experiments in a random grid scenario consists of the product of number of nodes by the number of coverage radius. For example, the first experiment consists of 2 nodes placed randomly with the constraint of the protocol assumption that it exists at least one possible path between any pair of nodes. Accordingly, the random placement algorithm selects a node (in this case node 1) and places next node (in this case node 2) within coverage of the previously chosen node. Figure 5 shows an arbitrary example with 10 nodes and coverage radius of 0.5.

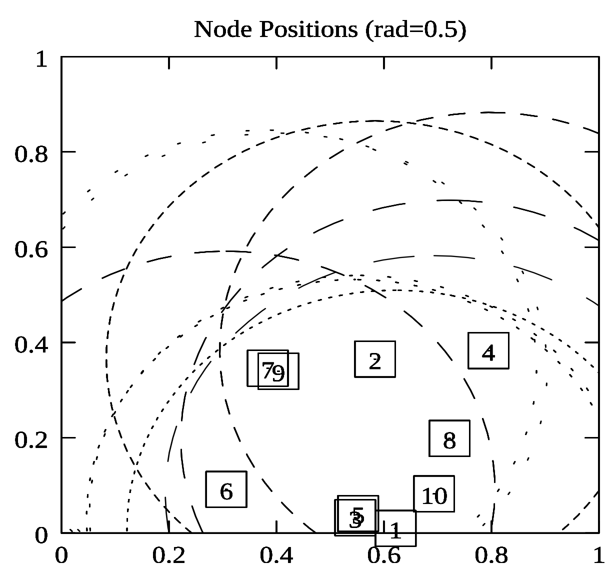

Figure 5: Random grid example

4. Measurements

The evaluation of the W2LAN protocol has been performed by using discrete event simulations. All simulations have been run in ad hoc networks ranging from 2 nodes up to 25 nodes. The nodes were placed into a one-unit side square. All simulations have been run during 1,000 units of simulated time and 10,000 units of simulated time, with variations in the cost results of less than 0.1%. Data traffic has been randomly generated with the negative exponential distribution (Poisson).

In order to simulate the coverage of each node the coordinates of any sender node have been introduced in the model, piggybacked into the frame header being sent. It should be noticed that this information is only used in simulations, and is not a part of the W2LAN protocol.

Another consideration to understand the measurements is the theoretical boundaries of the conversation cost. Given a set of *N* nodes and a conversation C_N, the number of announces is always *N*, since there is 1 node starting the conversation C_N and *N-1* nodes who eventually will have a data packet ready to be broadcast for C_N, and therefore they will announce C_N. Similarly, the number of requests is always *N-1*, since the node starting the conversation does not need to request C_N, and the rest of the nodes eventually will request C_N. Finally, the maximum number of data packets in the worst case scenario (i.e. linear grid, coverage radius equal to the distance between nodes) is *N-1*, which is repeating the data packet to each node.

5. Cost/Benefit analysis

The Cost/Benefit analysis of the W2LAN protocol, for each scenario under consideration, consists of finding out the average number of Data frames per conversation. In the sequel, the constant amount of Announce and Request frames (Section 4) are not taken into consideration to evaluate the cost of a conversation. Figures containing series of different number of nodes, coverage radius (x-axis) and number of frames per conversation (y-axis) are rendered for linear grid, square grid and random grid. From the regions of interest of the graphics, individual per node graphics can be depicted, offering additional detail to the analysis.

5.1 Linear grid

The results for the linear grid experiment depicted in figure 6 show that the number of Data frames per conversation is between 1 and 10, within the general theoretical boundaries. The first case of the range corresponds to the subset of experiments where all the nodes can see each other, that is, coverage radius of one unit (bottom right corner) independently of the number of nodes. The worst case for all the curves corresponds to the minimum coverage radius. This case has the particularity of having a deterministic result on number of frames per conversation. In a set of *N* nodes positioned as explained in section 3.1, the number of frames per conversation is *N-1* if the node is in the edge and *N-2* if it is not. The average number of nodes is expressed by:

$$\frac{N^2 - 2N + 2}{N} \qquad (1)$$

Then, this formula generates the values of the first point in each curve, which is also the theoretical upper bound of the linear grid.

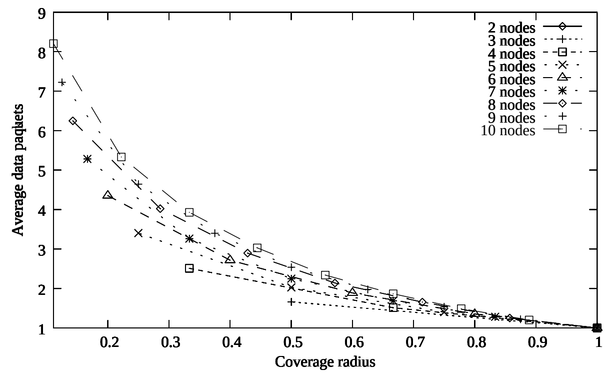

Figure 6: Results for 2…10 nodes

The intermediate values (non-deterministic) are within the theoretical range. The first value (worst case situation) has already been explained, and the following values monotonically decrease until the value of one, case of total visibility.

5.2 Square grid

The results for the square grid experiment displayed in figure 7 reveal that the number of frames per conversation is between 1 and 17 (25 nodes curve), considerably better –lower- than the generic theoretical boundaries (*N-1*, 24 in the case of 25 nodes). This is explained by the fact that the square grid geometry exploits the broadcast nature of the protocol, achieving this way an overall lower cost result.

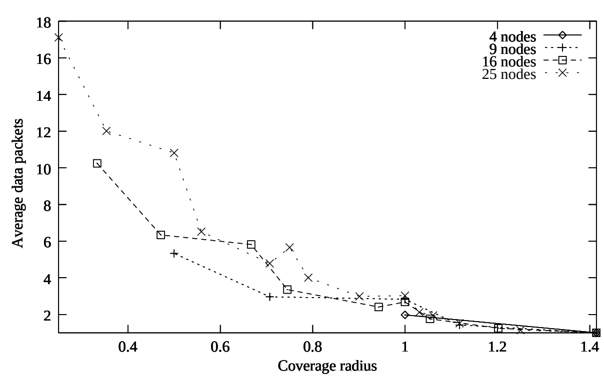

Figure 7: Results for 4, 9, 16 and 25 nodes

The first case of the range (bottom right corner) corresponds to the subset of experiments where all the nodes can see each other, that is, coverage radius of independently of the number of nodes.

The worst case for all the curves corresponds to minimum coverage radius. The values on this case, in comparison with linear grid, are much better: The curve of 25 nodes presents a value of 5.33 frames per conversation, that would correspond to 23.08 in a linear grid, and 24 as a general theoretical upper bound.

The rest of the values decrease until the value of one, case of total visibility, always within theoretical range.

5.3 Random grid

The results for the random grid experiment depicted in figure 8 are, at first glance, confusing.

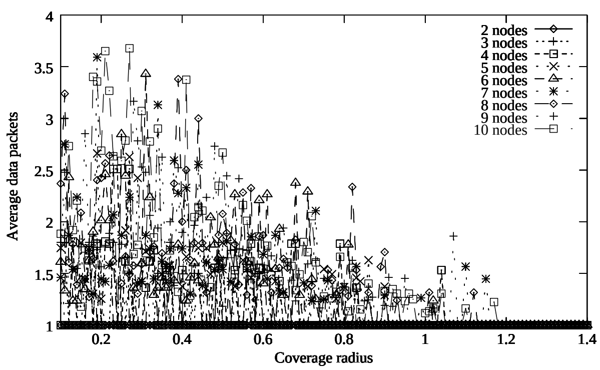

Figure 8: Results for 1…10 nodes

The reason of the divergence in consecutive experiments is the method of generating grids described in section 3.3. Every incremental step in the coverage radius generates a new random pattern connected network, with at least one multi-hop path between any two distinct nodes. That means that each point has been generated with a different node positioning. But, even with the confusion, it can be foreseen an average value with similar behaviour than in previous experiments. It can also be observed that the random grid behaves better than the previous scenarios, but again the way of generating patterns influences on this result. Figure 9 illustrates the 9-node graphic (a particular case of Figure 8), where it can be better observed the behaviour of the random curve. The average values of the curve decrease until the full coverage situation, with better values than square grid (Figure 7). The results are better because the algorithm of node placement favours node proximity, which in average represents fewer packets per conversation. It should be noticed that this situation is the most realistic one in a MANET environment.

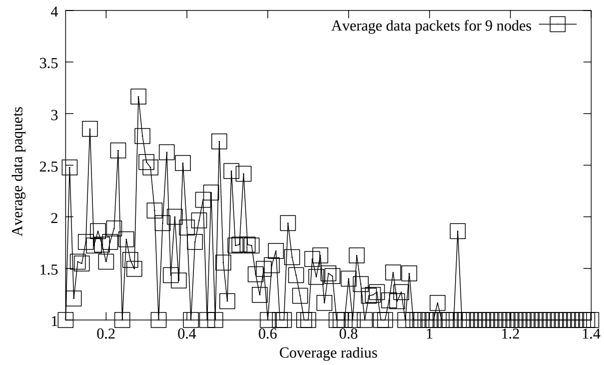

Figure 9: 9-node curve

6. Conclusion

In order to achieve the benefit of having total visibility among nodes (in any scenario where it exists at least one path between any pair of nodes), a price has to be paid. In the W2LAN case the price consists of a set of frames per W2LAN conversation. These frames are of three types: Announce, Request and Data. Both Announce and Request frames have a small fixed size (34 and 20 bytes respectively), and Data frames have the same size than an original Ethernet frame. The experiments performed have not assumed any specific size of Ethernet frames, although the original idea was using W2LAN as platform for the protocol MCDP-LAN [8], where the Ethernet frames being used are of the magnitude order of 1Kbyte. Therefore, the size of Data frames is two orders of magnitude bigger than Announces and Requests. Also, this environment consists usually in a set of terminals where most of them are within one hop distance and the rest are connected through short multi-hop links, positioned “randomly”. Under this circumstance the number of packets per conversation has been shown to be close to a conventional Ethernet LAN, with the W2LAN benefit of total visibility of the nodes from the point of view of higher layers.

Another scenario under study is a multicast environment, where major MANET protocols are challenged [9]. By the own nature of the W2LAN protocol it is expected that multicast communications challenges will be overcome.

4. Acknowledgements

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