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PERFORMANCE OF THREE ROUTING PROTOCOLS IN UWB AD HOC NETWORK DEPLOYED IN AN INDUSTRIAL APPLICATION

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Abstract - Ultra-Wideband (UWB) transmission technique is supposed to be a promising candidate for multi-hop mobile ad hoc networks in short range scenarios. In multi-hop networks, routing protocols are needed to establish connections between nodes. This paper presents a performance evaluation of the On-Demand Distance Vector Routing protocol (AODV), Dynamic Source Routing protocol (DSR), and Optimized Link State Routing protocol (OLSR) considering a realistic multi-hop ad hoc network scenario. This scenario represents an industrial indoor application that uses UWB transmission technique. The evaluation is accomplished through simulation using a joint PHY/MAC architecture for 802.15.4a-like UWB ad hoc networks combined with a realistic pathloss model. In this evaluation, the effects of multi-hop, data rate, and scalability on routing performance of AODV, DSR and OLSR are investigated. Based on the observed results, we specify two basic approaches to design a routing protocol suitable to our proposed network scenario.

I. INTRODUCTION

Wireless communication networks have recently witnessed the introduction of a promising transmission technology called Ultra-Wideband (UWB). An UWB system is defined as a radio system that has a 10-dB bandwidth that is either larger than 20% of its center frequency or occupies 500 MHz or more [1]. UWB technique has been investigated intensively in the last few years due to its attractive properties such as high data rates, very low transmission power, spectrum reuse, robust performance under multipath conditions, multiple access capabilities and high resolution position location and tracking.

In ad hoc networks, devices (or nodes) are connected via wireless links that are established and used spontaneously without relying on a pre-existing infrastructure. All nodes of ad hoc networks operate as routers and they cooperate to forward data packets to reach destinations that are not within the transmission range of the source nodes, and thus forming a multi-hop Mobile Ad Hoc Network (MANET). A vast variety of routing protocols designed for the use in MANET exists in the literature. An UWB ad hoc Network (UWBNet) is a collection of nodes interconnected by UWB links. The IEEE 802.15 Low Rate Alternative PHY Task Group (TG4a) for Wireless Personal Area Networks (WPANs) [2] is aiming to standardize two alternative physical channels based on UWB technology.

This paper presents a performance evaluation of three popular ad hoc routing protocols in order to specify the basic requirements needed to design a suitable routing protocol for a realistic multi-hop ad hoc network scenario in which UWB transmission technique is used. The rest of the paper is organized as follows. In section II we present some related works. Section III describes our simulation environment. The performance evaluation is discussed in section IV. Then we summarize our findings and draw our conclusions in section V. Finally, future work is given in section VI.

II. RELATED WORK

Many performance evaluations of ad hoc routing protocols have been carried out in the last decade. Most of these studies assume a primitive Physical (PHY) layer model and a random way point scenario, e.g., [3] and [4]. Very few studies consider a realistic scenario with a very simple realistic PHY model, such as [5].

However, our study differs from the previous ones substantially. Firstly, we considered a PHY layer model that uses a realistic pathloss model called shadowing model [6] combined with an UWB transmission technique. Secondly, we considered a network scenario that represents an industrial indoor application. In this scenario, we considered realistic mobility and traffic patterns as well. To the best of our knowledge, this is the first performance evaluation study of AODV, DSR and OLSR in such a realistic network scenario.

III. SIMULATION ENVIRONMENT

The simulation is carried out using the well-known simulator ns-2 [7] version ns-allinone-2.29.3 running under SUSE Linux 10.1 operating system. In the following subsections we will describe our simulation environment.

A. UWB PHY and MAC Layers

The received power at certain distance from the transmitter can be described as a random variable due to multipath propagation effects, which are also known as fading effects. To reflect UWB pathloss model in the PHY layer, the shadowing model described in [6] is used. In this model, the pathloss in decibels at a certain distance $\boldsymbol{d}$ is given by

$$\boldsymbol{PL}(\boldsymbol{d}) = \left[\boldsymbol{PL_o} + 10\boldsymbol{\beta}\log_{10}\left(\frac{\boldsymbol{d}}{\boldsymbol{d_o}}\right) + \boldsymbol{S}(\boldsymbol{d})\right],\ \boldsymbol{d} \geq \boldsymbol{d_o} \qquad (1)$$

where $\boldsymbol{PL_o}$ is the pathloss at the intercept point $\boldsymbol{d_o}$ which is usually equals to 1m, $\boldsymbol{\beta}$ is the pathloss exponent and $\boldsymbol{S}(\boldsymbol{d})$ is the log-normal shadow fading that reflects the variation of the received power at certain distance. $\boldsymbol{S}(\boldsymbol{d})$ is considered to be a

Gaussian random variable with zero mean and a standard deviation $\boldsymbol{\sigma_S}$. Depending on our network scenario (that will be described later in this section), the values of $\boldsymbol{PL_o}$, $\boldsymbol{\beta}$, and $\boldsymbol{\sigma_S}$ are 56.7dB, 2.15, and 6dB respectively [8].

The above UWB pathloss model with a joint PHY/MAC architecture for an 802.15.4a-like UWBNet is implemented in ns-2 [9] and the code version ns-2.29-uwb-0.10.0 is used [10]. This architecture is based on a Time-Hoping Impulse-Radio UWB (TH-IR-UWB) system with 3 main components: interference mitigation; dynamic channel coding that continuously adapts the bit rate to variable channel conditions and interference; and a private MAC that resolves contention for the same destination. The explanation of this architecture is beyond the scope of this paper. See [11] for full description of it. To justify the use of UWBNet, Wireless Local Area Network (WLAN) model operating with IEEE 802.11a standard [12] is also used in the same frequency band, bit rate, and shadowing model as in UWBNet.

B. Routing Protocols

MANET working group [13] is trying to standardize only two routing protocols based on AODV, DSR and OLSR. Current candidates are DYMO [14] as a reactive protocol and OLSRv2 [15] as a proactive protocol. However, we did not use these two routing protocols in our evaluation since they are immature in terms of implementations. Moreover, they are basically developed from AODV and OLSR and differ mainly in packet header format. Therefore, we expect that studying the performance of AODV, DSR and OLSR will give a strong clue about the performance of DYMO and OLSRv2.

The above used version of ns-2 supports AODV and DSR routing protocols. However, OLSR is not included so far. Therefore, we used the UM-OLSR implementation version 0.8.8 [16]. In the following subsections, we give brief descriptions of AODV, DSR and OLSR.

1) Ad Hoc On-Demand Distance Vector

AODV [17] is a pure on demand approach by which each node maintains a routing table for active destinations only. In AODV sequence numbers are used to avoid looping problems. When a source node wants to send a packet to a destination with no valid route, a route discovery procedure is initiated by sending a Route Request (RREQ) packet through the network. RREQ does not contain a complete path with all addresses of involved nodes. It contains the address and the last known sequence number for the destination and source nodes, hop count initialized to zero and a RREQ ID. The source address together with the RREQ ID uniquely identifies a RREQ and can be used to detect duplicates.

A node can reply to a RREQ only if it has a corresponding sequence number greater or equal to that contained in the RREQ. This ensures that a fresh route is selected and also guarantees loop freedom. Once the RREQ has reached the destination or an intermediate node with a valid route, a Route Reply (RREP) packet is sent back to the source via a unique path because nodes forward it only to the node from which they received the RREQ. If the source receives more than one RREP, it selects the route with the greatest sequence number and smallest hop count. Thus, AODV stores only one route per destination in its route table with a certain lifetime.

When a node detects a break in one of its outgoing links, it creates a Route Error (RERR) packet containing a list of all the destinations that are now unreachable and sends it to its neighbors that were also using the lost link. If the route is still needed, a new path discovery procedure is activated.

2) Dynamic Source Routing

DSR [17] is also a reactive routing protocol like AODV but it has a few important differences. DSR is a source routing protocol. When a source node wants to send a packet to a destination with no valid route, a route discovery procedure is initiated by sending a RREQ through the network. When an intermediate node forwards RREQ, it adds its own address to the route record of the packet. It forwards it only if its own address does not already appear in the route record (to avoid loops). Thus, when RREQ arrives to destination it contains a complete path from source to destination. When RREQ reaches the destination or an intermediate node with a valid route to the destination, a RREP is generated. If the node knows a valid route to the source it can use it to send RREP. Otherwise, it uses the reverse path contained in RREQ.

Route maintenance in DSR is accomplished using RERR messages and acknowledgements. RERR message is sent to the original sender of the data packet when a link breaks. Acknowledgements are used to verify the correct operation of the links in a path from source to destination. Another characteristic of DSR is the fact that DSR uses route cache which allows multiple route entries to be maintained per destination. Thus, an alternate route can be used when a link breaks. In addition, the route cache entries do not have lifetimes. A route remains in route cache until it breaks.

3) Optimized Link State Routing

Unlike AODV and DSR, OLSR [18] is a proactive link state routing protocol which is mainly characterized by 3 elements. Neighbor Sensing: Two nodes are considered as neighbors if there exists a link between them which can be symmetrical or not. Two nodes are two-hop neighbors if they have a common neighbor to which they are related via symmetrical links. Each node periodically emits "hello" messages containing its own address, the addresses of its all known neighbors and the state of the link with them (uni- or bi-directional). Therefore, each node can maintain information about its neighborhood up to two hops. This information has life time and must be refreshed at regular intervals. Message Flooding: In OLSR, message flooding is optimized in order to avoid unnecessary transmissions. Therefore, each node selects Multi-Point Relays (MPR) among its neighbors. The only requirement for the algorithm of choice is that a message relayed by MPR must reach all the two hop neighbors of the sender. A node is informed that it is MPR through "hello" messages. A MPR relays only the messages from the nodes by which it has been elected as MPR. Topological information: All the nodes that are MPR for at least one node periodically broadcast a

Topology Control (TC) message. A TC message contains the address of the sender and addresses of all the nodes for which it is MPR. By this way all the nodes can make a partial topology graph containing all reachable nodes and the set of links between MPR and their selectors. An algorithm can then calculate the optimum path to any node.

C. *Network Scenario*

A production line is a set of sequential operations established in a factory by which materials are put through a refining process to produce an end-product that is suitable for onward consumption; or components are assembled to make a finished article [19]. Our network scenario represents a production line in a factory, i.e., an industrial indoor application. The production line consists of two main components: materials boxes moved by a conveyor belt and machines that manipulate the materials. In order to control the production process, it is intended to interconnect the machines with each other through the moving material boxes. Consequently, a multi-hop MANET is formed. The links between nodes is established using UWB technology.

As shown in Fig. 1, the network consists of fixed nodes (machines) and mobile nodes (material boxes) distributed along a linear topology at regular distances. Distance between fixed nodes is basically 30m, while distance between mobile nodes is varied from 1 to 30m. The mobile nodes are moving from one side to the other with constant speed of 1m/s. The network size is varied from 2 to 9 fixed nodes. Each fixed node sends basically one data packet to the next fixed node (in direction of movement) every 30s using TCP connections. The size of this data packet is 1024 bytes and it contains information (codes numbers) about the mobile nodes moving between the two fixed nodes. In other words, there is one data traffic flow between each two successive fixed nodes with data rate of 0.27Kb/s that we will call it the basic data rate. This data rate is sufficient to control the manufacture process and it is low enough to be used in 802.15.4a-like networks within a noisy environment.

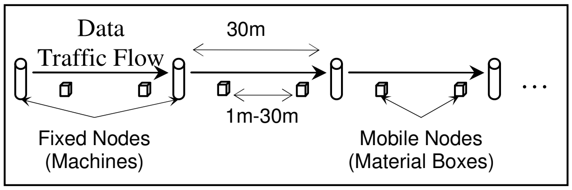


Fig. 1: Production Line Topology.

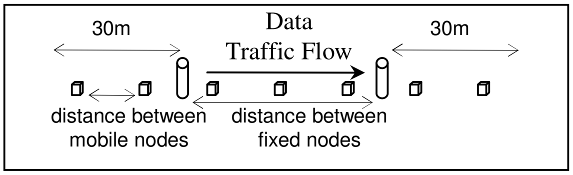


Fig. 2: a Production Line with 1 Data Traffic Flow.

The bit rate is variable (1.8Mb/s – 18Mb/s) since it depends on the channel code being used [11]. The transmission range of nodes is also variable and it depends also on channel coding [9]. Center frequency is 5GHz. The simulation time is 750s and it includes a warming up period of 150s. All packets exchanged during this period are discarded and not included in computations. Therefore, the actual simulation time is 600s. Each simulation experiment is repeated 50 times and their average has been used. Our simulation codes and parameters default settings are freely available [20].

IV. PERFORMANCE EVALUATION

In the above described network scenario, we compared the performance of AODV and OLSR in UWBNet and WLAN. Also we compared the performance of AODV, DSR and OLSR in UWBNet. We investigated 3 performance metrics:

- Packet Delivery Ratio (PDR),
- Normalized Throughput (NTh) and
- Routing Overhead Ratio (ROR).

PDR is the ratio between the total received data packets without duplication to the total sent data packets. NTh is the ratio between the useful received data packets (without duplication and retransmissions) to the total data packets that should be transmitted during the actual simulation time. ROR is the ratio between the cumulative sum of bytes of all routing packets exchanged in the network in order to send data packets to the cumulative sum of bytes of these routing packets and all sent data packets at routing level. PDR and NTh are important metrics for best-effort traffic, while ROR metric evaluates protocol efficiency.

For clarity reasons, the simulation results are plotted in smoothed curves using 5-points moving average filtering method implemented in the function *smooth* of MATLAB [21] version 7.4.0.287 (R2007a). For each curve, the 90% confidence intervals including the error introduced by smoothing method are plotted as well. In the following subsections we will discuss the simulation results.

A. *Multi-hop Investigation*

Here we describe the multi-hop effect on NTh of AODV and OLSR in UWBNet and WLAN. To do so, a production line with one traffic flow is used as shown in Fig. 2. The network consists of two fixed nodes and mobile nodes moving from one side to the other. The distance between fixed nodes is varied to take the values 10m, 20m, and 30m. For each of these values, the distance between mobile nodes is varied from 1m to 30m. Data traffic consists of only one flow between the two fixed nodes with the basic data rate of 0.27Kb/s and using TCP connections. Length of the production line equals to the distance between the two fixed nodes plus 30m before the first fixed node and 30m after the second fixed node. Therefore, number of nodes in the network is variable and it is between 5 and 93 nodes depending on the distance between fixed and mobile nodes. The results are shown in Fig. 3 and Fig. 4.

When the distance between the two fixed nodes is 10m, the communication between them is done mainly in one hop (direct connection link). As shown in Fig. 3(a), the effect of nodes density appears clearly in UWBNet because the used UWBNet MAC model is more sensitive to the interference level than WLAN MAC model (see section III). Large distance between mobile nodes means low node density, and thus low interference level. As the distance decreases, the nodes density increases and this leads to higher interference level. This explains why NTh in UWBNet decreases as the distance between mobile nodes is being decreased.

When the distance between the two fixed nodes is 20m, the communication between them is done mainly in two hops, and thus, the multi-hop effect on NTh obviously appears. As shown in Fig. 3(b), NTh maximum occurs at the transmission range of the nodes. When the distance between mobile nodes is smaller than the transmission range, there are extra nodes than what are needed for multi-hop routing and this leads to higher interference level. Thus NTh decreases. As the distance between mobile nodes becomes larger than the transmission range, there are insufficient nodes for multi-hop routing. Accordingly, NTh decreases also in this case. This is true for both UWBNet and WLAN.

When the distance between the two fixed nodes is increased to 30m, the communication between them is done mainly in three hops. Fig. 3(c) shows clearly that UWBNet model achieves a much better NTh than WLAN model in multi-hop communications with hop count larger than two. Similar results are obtained when OLSR is used as shown in Fig. 4. This justifies the use of UWB transmission technique in our network scenario.

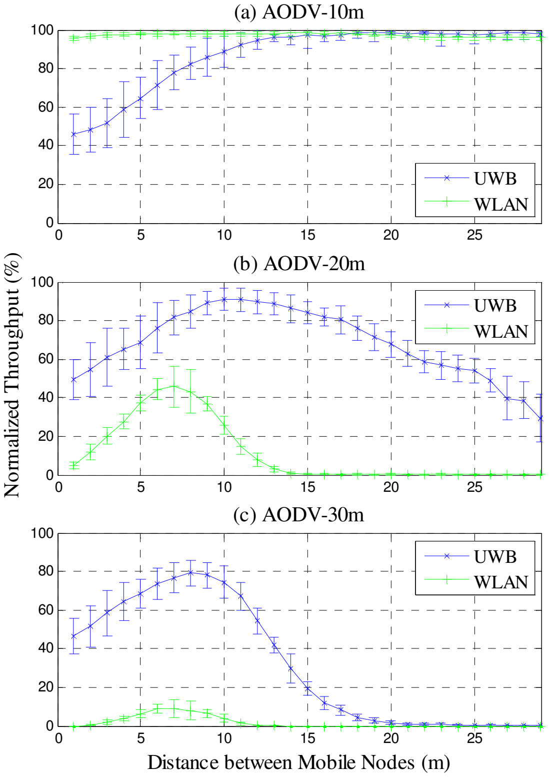


Fig. 3: Multi-hop Effect on NTh of AODV.

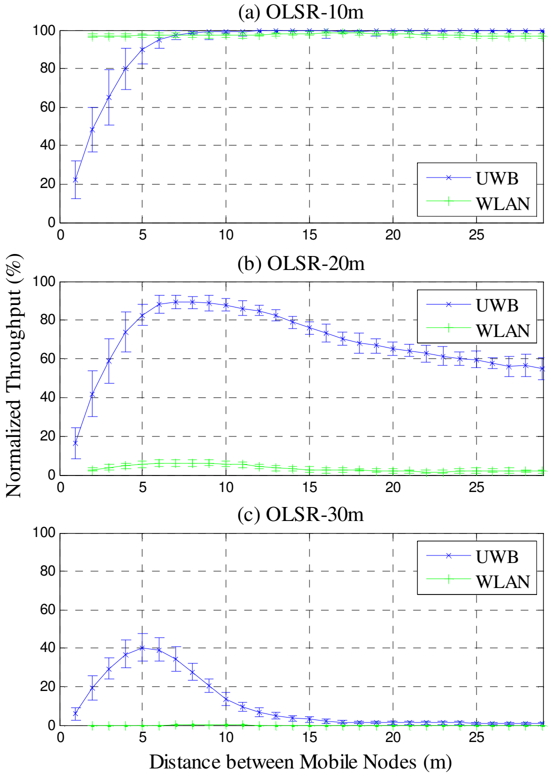


Fig. 4: Multi-hop Effect on NTh of AODV.

B. *Data Rate Investigation*

The production line with one data traffic flow shown in Fig. 2 is used to investigate the data rate effect on the performance of AODV, DSR and OLSR in UWBNet. The distance between the two fixed nodes is set permanently to 30m, while the distance between mobile nodes is varied from 1m to 30m. Data rate of the data traffic flow is varied by sending one data packet of size 1024 bytes from one fixed node to the other every 30s (0.27Kb/s), 10s (0.82Kb/s), and 5s (1.64Kb/s) using TCP connections. The results are shown in Fig. 5, Fig. 6, and Fig. 7. Furthermore, data packets distribution ratios, with respect to the total useful data packets that should be transmitted, are shown in Fig. 8, Fig. 9, and Fig. 10 in the cases of AODV, DSR, and OLSR respectively.

With higher data rates more data packets are sent. In the case of AODV, this will lead to initiate more route discovery and maintenance procedures. As more route procedures become vulnerable to link breaks, more data packets are not delivered. Hence, as data rate increases, the ratio of undelivered data packets will increase as shown in Fig. 8. This is reflected in lower PDR as seen in Fig. 5(a). As a result, NTh in Fig. 6(a) decreases as data rate increases. The same behavior is noticed in case of DSR for PDR, NTh, and data packet distribution as shown in Fig. 5(b), Fig. 6(b), and Fig. 9 respectively. In contrast, in the case of OLSR, routing tables are built proactively. Hence, data packets are sent immediately and need not to wait until a route is discovered. Moreover, OLSR supports asymmetrical links which are very common in this noisy environment. Consequently, as data rate increases more data packets are delivered as shown in Fig. 10. This is reflected in higher PDR as seen in Fig. 5(c). As a result, NTh in Fig. 6(c) increases as data rate increases.

By comparing ROR of the three routing protocols shown in Fig. 7, it is found that AODV has the lowest ROR, particularly for low data rate. But AODV tends to use route discovery and maintenance procedures frequently. Therefore, as the amount of data packets increases in the network, more routing packets are generated as well, and thus ROR of AODV is not affected by the increase of data rate and it remains almost at the same level.

On the other hand, DSR and OLSR have different behaviors. DSR does not tend to use frequent routing procedures since it stores multi-routes in its route cache for the same destination without time limit. Therefore, a relative increase in data packets will not results in a same increase ratio in routing packets. In the case of OLSR, the routing tables are built proactively. For the same number of nodes, the same routing tables are built independently from the data rate even if there is no data packet to send. This explains why ROR of OLSR and DSR decrease as data rate increases.

AODV outperforms DSR in this scenario. This is because DSR has no mechanism to delete out-of-date routes from its route cache. As a result, a very low delivery ratio of data packets is noticed in Fig. 9. Thus, DSR has much lower PDR and much higher ROR, which leads to lower NTh as shown in Fig. 5, Fig. 7, and Fig. 6 respectively. Also in this scenario, AODV outperforms OLSR in the case of low data rate. As data rate increases, OLSR begins to outperform AODV in terms of PDR and NTh as shown in Fig. 5 and Fig. 6. Moreover, at high data rates, ROR of OLSR is expected to be lower than that of AODV as Fig. 7 shows.

Another observation noticed in our scenario is the large amount of data retransmissions in case of the three protocols, and the small amount of data duplication in case of AODV and DSR as shown in Fig. 8, Fig. 9, and Fig. 10. This is due to the frequent link breaks occurring in such noisy environment. Notice that data retransmissions in case of AODV and DSR are more obvious at low data rates. As data rate increases, these retransmissions decreases since the amount of received data packets itself decreases. These extra retransmissions and duplication are considered as an additional useless overhead that consumes network capacity. For example, as seen in Fig. 8(a), in addition to almost 80% of useful data packets received at 10m distance between mobile nodes, there is about 140% of useful data packets retransmitted and duplicated, in addition to the routing overhead.

One more remarkable observation is that there is no data duplication in the case of OLSR as shown in Fig. 10. This is because routing tables in OLSR are built using a more controllable procedure since TC messages are not flooded by any node (as in AODV and DSR), but only by MPR nodes. Thus, OLSR is protected against data duplication by limiting the number of forwarding nodes and centralizing some tasks in the network.

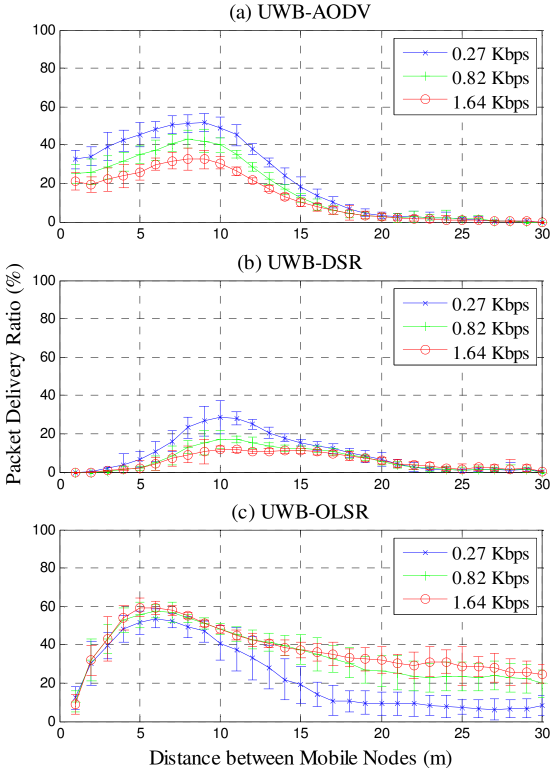


Fig. 5: Data Rate Effect on PDR of 3 Routing Protocols.

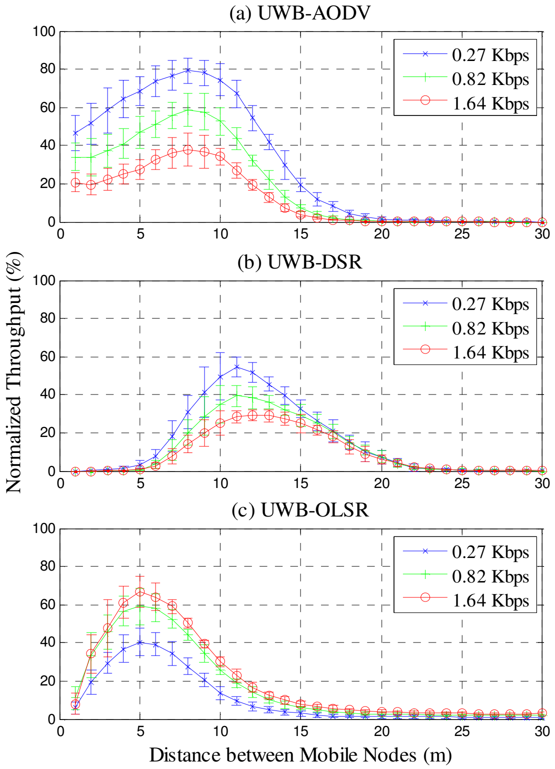
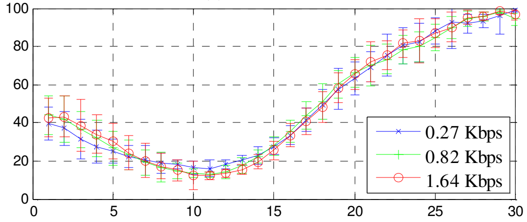
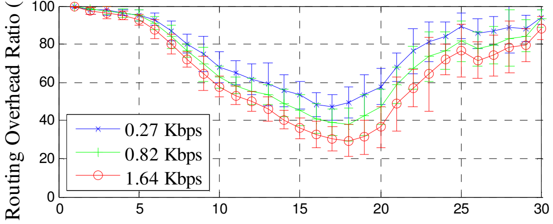


Fig. 6: Data Rate Effect on NTh of 3 Routing Protocols.

(a) UWB-AODV



(b) UWB-DSR



(c) UWB-OLSR

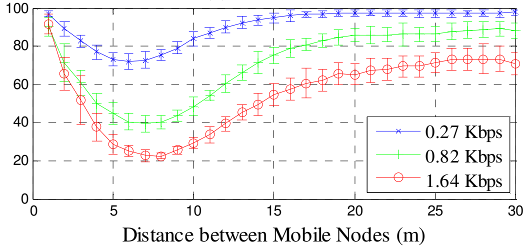
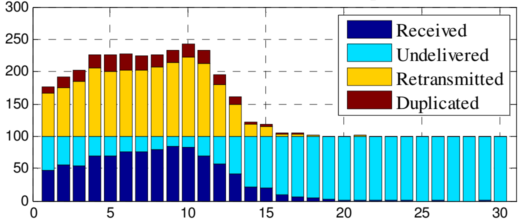
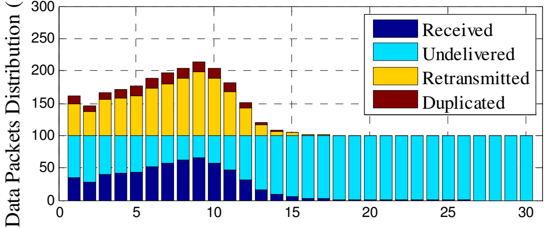


Fig. 7: Data Rate Effect on ROR of 3 Routing Protocols.

(a) UWB-AODV-0.27 Kbps



(b) UWB-AODV-0.82 Kbps



(c) UWB-AODV-1.64 Kbps

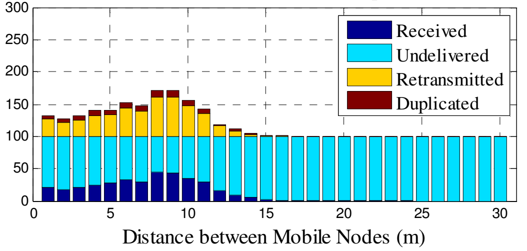
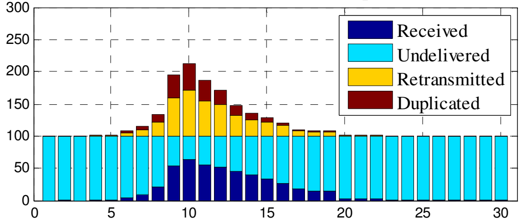
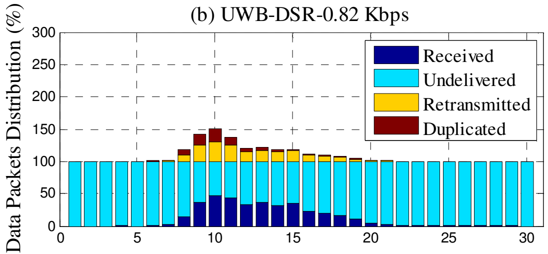


Fig. 8: Data Rate Effect on AODV Data Packets Distribution.

(a) UWB-DSR-0.27 Kbps



(b) UWB-DSR-0.82 Kbps



(c) UWB-DSR-1.64 Kbps

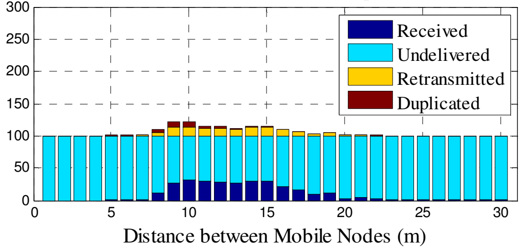
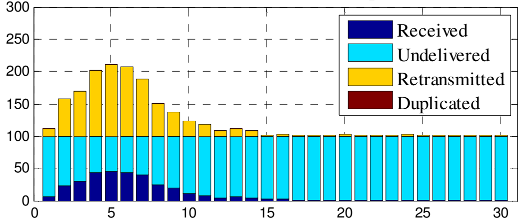
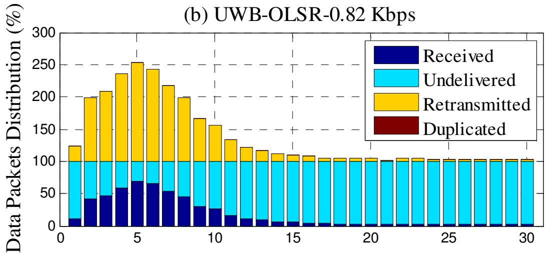


Fig. 9: Data Rate Effect on DSR Data Packets Distribution.

(a) UWB-OLSR-0.27 Kbps



(b) UWB-OLSR-0.82 Kbps



(c) UWB-OLSR-1.64 Kbps

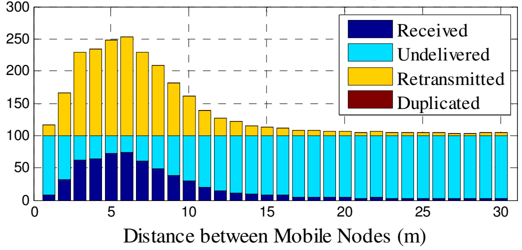


Fig. 10: Data Rate Effect on OLSR Data Packets Distribution.

C. *Scalability Investigation*

Here we describe the scalability of AODV and OLSR in UWBNet. Production lines with 1, 3, and 8 data traffic flows are used. Fig. 11 shows production lines with 1 and 3 data traffic flows. The distance between fixed nodes is always 30m, while the distance between mobile nodes is varied from 1m to 30m. Data traffic consists of only one flow between each two successive fixed nodes with the basic data rate of 0.27Kb/s and using TCP connections. Length of the production line equals to 30m multiplied by number of flows plus 30m before the first fixed machine and 30m after the last fixed machine. Number of fixed machines equals to the number of flows plus one while number of mobile nodes is variable and depends on the distance between them and the number of data traffic flows. The results are shown in Fig. 12 and Fig. 13. In addition, data packets distribution ratios, with respect to the total useful data packets that should be transmitted, are shown in Fig. 14 and Fig. 15 in the cases of AODV and OLSR respectively.

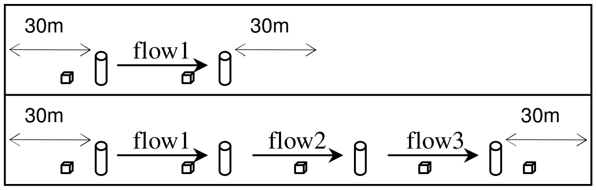
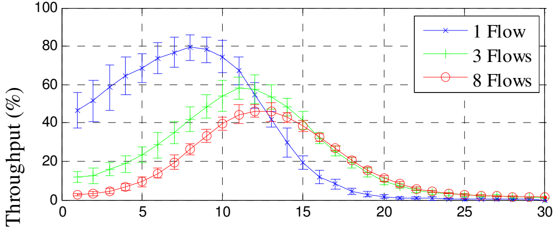


Fig. 11: Production Lines with 1 and 3 Data Traffic Flows.

In this scenario, as flows number increases, number of nodes in the network increases as well. Larger number of nodes leads to higher interference level and thus more frequent link breaks occur. In the case of AODV, as flows number increases, more route procedures are exposed to the link breaks. Hence, as flows number increases, more data packets are not delivered as shown in Fig. 14, and hence NTh decreases at high density of mobile nodes as shown in Fig. 12(a). However, at low density of mobile nodes (when distance between mobile nodes is greater than 12m), the situation is the opposite, i.e., as flows number increases, NTh increases but still lower than the maximum at transmission range. This looks abnormal for the first moment. However, this can be simply justified.

Fig. 11 depicts our network scenario at a certain time. Assume that the distance between mobile nodes is 22m (distance between fixed nodes is 30m). In the case of 1 data traffic flow, there is no link between the two fixed machines since the distance between the source node and the mobile node is 22m and NTh is almost zero above 20m, see Fig. 12(a). This is true also for flow1 in the case of 3 data traffic flows assuming the same environment conditions. However, for flow2, the mobile node is 14m apart from the source node and 16m away from the destination node. At these distances multi-hop links may exist between the source and destination nodes. The same thing can be said about flow3. Therefore, in this example of Fig. 11, flow1 is impaired in both cases of 1 and 3 data traffic flows, while flow2 and flow3 are not in the case of 3 data traffic flows. This explains why NTh of AODV in the case of 1 flow is almost zero at 22m while it is greater than zero in the cases of 3 and 8 flows as shown Fig. 12(a).

(a) UWB-AODV



(b) UWB-OLSR

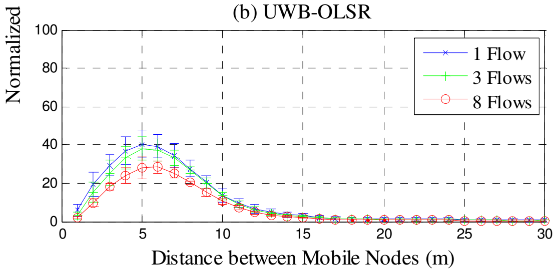
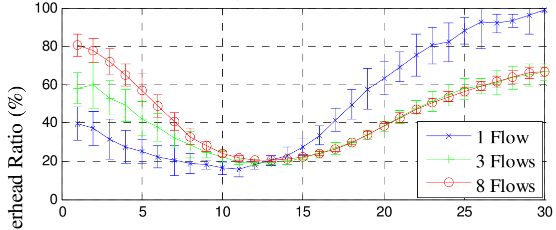


Fig. 12: Scalability Effect on NTh of AODV and OLSR.

(a) UWB-AODV



(b) UWB-OLSR

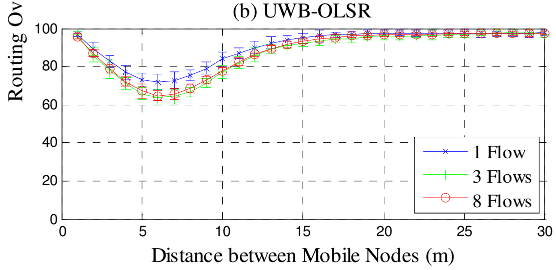


Fig. 13: Scalability Effect on ROR of AODV and OLSR.

An almost similar behavior is noticed in ROR of AODV shown in Fig. 13(a), i.e., as flows number increases, ROR increases at high density of mobile nodes, while at low density of mobile nodes the opposite is observed. This means that ROR of AODV does not remain constant as flows number increases since both data traffic and number of nodes increase.

In case of OLSR, the variations in NTh and ROR are very small as flows number is increased as shown in Fig. 12(b) and Fig. 13(b). Therefore, the conversion in the behaviors of NTh and ROR between low and high density of mobile nodes are not noticeable. Furthermore, as we said before, when flows number increases not only data traffic increases but also number of nodes. As number of nodes increases in the network, each node needs more time to create longer routing tables due to the proactive nature of OLSR. Therefore, routing overhead grows as flows number increases. As a result, ROR of OLSR does not decrease and stays at high levels as shown in Fig. 13(b). High ROR means that nodes send more routing packets than data packets. Hence, as shown in Fig. 15, the ratio of received data packets decreases as flows number increases. Consequently, as shown in Fig. 12(b), NTh of OLSR decreases as flows number increases.

V. SUMMARY AND CONCLUSIONS

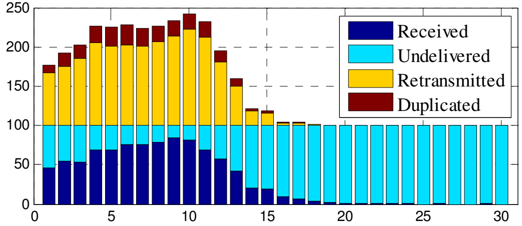
Although AODV and DSR are both on-demand ad hoc routing protocols, they differ in their routing mechanisms. AODV uses routing tables, one route per destination, time threshold to delete inactive routes, and destination sequence number to prevent loops and to determine the freshness of a route. On the other hand, DSR uses source routing and cache routes that maintain multiple routes per destination. DSR does not rely on any periodic or timer-based activities. On the other hand, OLSR is a proactive routing protocol that is optimized by limiting the number of forwarding nodes and centralizing some tasks in the network. This is done for two reasons: to reduce routing overhead using MPR node concept by which the information about the 2-hops neighborhood is flooded only; and to increase reactivity to topological changes.

The differences in routing mechanism of AODV, DSR, and OLSR lead to different performance results. After justifying the use of UWB technology instead of WLAN technology in an ad hoc network scenario that represents a production line in a factory, a performance comparison of AODV, DSR, and OLSR was carried out. We found that AODV outperforms DSR in our network scenario. In addition, AODV outperforms OLSR in small networks with low data rates (less than almost 1Kb/s). When data rate increases (greater than 1Kb/s) without increasing the network size, OLSR outperforms AODV. However, the performance of OLSR degrades as network size increases and AODV again outperforms it.

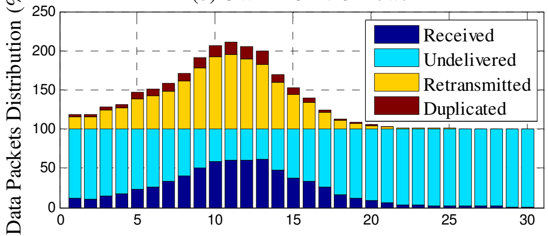
Each routing protocol has some routing mechanisms that will lead to better routing performance if they are combined in one routing protocol designed for our network scenario. In this scenario, the communications between fixed nodes is done mainly in 3 hops. Therefore, by combining source routing with multiple routes per destination (DSR mechanisms) with a time threshold to delete old routes (AODV mechanism), the problem of stale routes (drawback of DSR) will be solved and the need to use frequent route discovery process (drawback of AODV) will be reduced. Also, by centralizing some routing tasks such as message flooding (OLSR mechanism), data packet duplication (AODV and DSR drawback) will be eliminated.

Another approach to improve the routing performance is to use a sort of proactive routing mechanism. In our scenario, every fixed node is sending information about the moving nodes to the next fixed node regularly. Therefore, fixed nodes can exploit this information to maintain and update routing tables automatically without the use of routing control packets, since the speed and location of mobile nodes can be easily determined in this scenario. As a result, routing overhead for large network size will be decreased (OLSR drawback), and hence, the throughput will be increased.

(a) UWB-AODV-1 Flow



(b) UWB-AODV-3 Flows



(c) UWB-AODV-8 Flows

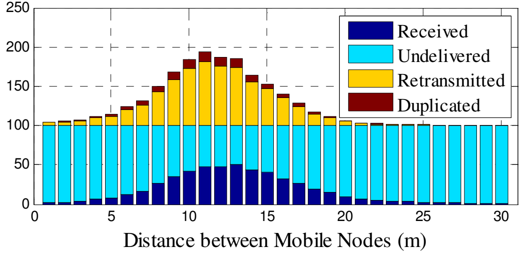
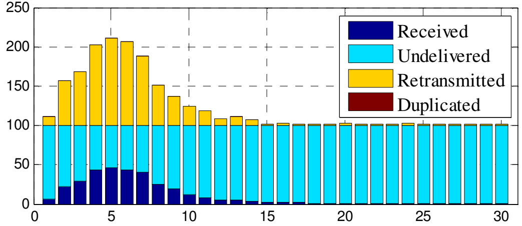
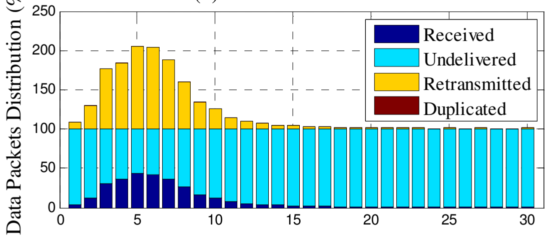


Fig. 14: Scalability Effect on AODV Data Pack. Distribution.

(a) UWB-OLSR-1 Flow



(b) UWB-OLSR-3 Flows



(c) UWB-OLSR-8 Flows

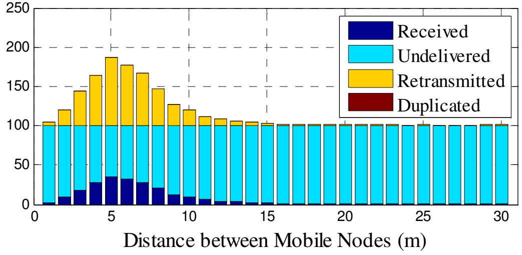


Fig. 15: Scalability Effect on OLSR Data Pack. Distribution.

VI. FUTURE WORK

A new routing protocol suitable for the production line scenario will be designed based on the two suggested approaches in the previous section. This routing protocol will be implemented in ns-2 simulator. Then the performance of the new routing protocol will be investigated and compared to the performance of AODV, DSR and OLSR.

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