An Interference Aware Approach for Routing in UWB Networks

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***Abstract*—Ultra Wideband (UWB) is a promising technology thanks to its unique physical characteristics. For this purpose, many works have already treated issues regarding UWB system. Most of them analyzed only first two ISO/OSI levels, that are physical and MAC layers, while too few investigations are yet spent on the routing layer of UWB systems. However, traditional approaches are not valid for UWB systems because they do not take into account of interference between nodes, that is not a trivial problem in these networks. The main goal of our work is to propose a new on demand routing protocol, called Interference Aware-based Ad-hoc on Demand Distance Vector (IA-AODV), based on the concept of interference perceived by the nodes: so, the optimum route is chosen on the basis of the minimum perceived interference, improving in this way the general system performance. To test the proposed protocol a ns-2 based simulator was realized. The protocol was compared with the AODV and IBOR protocols in terms of packet delivery ratio, end-to-end delay and normalized overhead. Simulation results show as our protocol outperforms the others protocols in all considered scenarios: only in few cases IA-AODV presents an overhead slightly higher than AODV.**

Index Terms*— *Interference-aware routing protocol; UWB routing layer; DCC-MAC based communications.

I. INTRODUCTION

Ultra wide band Ultra Wideband (UWB) is a technology based on the transmission of signal pulses of very short duration (typically the duration is a few nanoseconds) [1]. In the literature, many works have approached problems related to physical and MAC layers of UWB system, but, at the best of our knowledge, few studies are dealt with the UWB routing issues. However, traditional ad-hoc network approaches, based for example on minimum hop count or geometric criterions, can be inadequate for these network because UWB system are strongly affected by the mutual interference between nodes. The interference is the most undesired problem in wireless network and it can cause an irretrievable degradation of communications [1]. Therefore, a routing protocol, that does not take into account directly interference "between the nodes, could lead to choose a path wrong in terms of degradation of the signal: the distance between the source and destination can be minimized, but the level of interference may be too high if new metric are not defined in the routing protocols. For this reason a new protocol based on the concept of interference is proposed in this work. The proposed routing protocol employs as physical and MAC layers the *Dynamic Channel Coding-MAC* (DCC-MAC) model [2]. This MAC protocol allows devices to perform multiple parallel transmissions, adapting communications on the basis of interference perceived by the same devices. Furthermore, DCC-MAC employs an UWB impulse radio physical layer based on *time-hopping* (TH-UWB IR) as in ([3],[4]). Our protocol, called *Interference Aware-based Ad-hoc on Demand Distance Vector* (IA-AODV), lays its foundation in the classic *Ad-hoc On Demand Distance Vector* (AODV) protocol [5], of which inherits part of working operation and control packets, and in the *Interference Based On-Demand Routing Protocol* (IBOR) protocol [6], from which inherits the introduction of the interference concept in the selection of the optimum route. The novelty of the proposal is in the metric adopted for the choice of the optimal route from the source to the destination: it is not based on the hop number, as the classic AODV, or on the global interference perceived by nodes, as IBOR protocol, but on the interference affecting the links involved in the transmission. In order to analyze the IA-AODV protocol, a ns-2 simulator was realized and a comparison with AODV and IBOR protocols is carried out.

The paper is organized in this way: the related works are presented in section II; reference scenario is described in section III; IA-AODV protocol is well explained in section IV; performance evaluation is shown in section V and finally conclusions are summarized in section VI.

II. RELATED WORKS

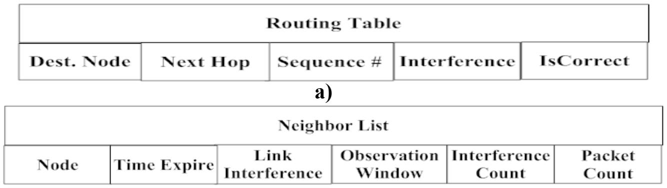
The classic ad-hoc network routing protocols, employing metrics as minimum hop counting or geometric criterions, can be useful in those architectures that are not affected by neighbor interference, but they are not valid for the UWB networks. The traditional routing protocols used in ad-hoc networks, as the AODV [5], *Dynamic Source Routing* (DSR) [7], and others ([8],[9]), does not take into account directly interference "between the nodes". In this way, the choice of a path, on which the packets must travel from the source to destination, may be wrong in terms of degradation of the signal: the distance between the source and destination can be minimized, but the level of interference may be too high if new metric are not defined in the routing protocols.

Transmission interference is the most undesired problem for wireless communications. In the last few years, many new techniques have been proposed in order to reduce the effects of the interference, defining interference-aware metrics and routing protocols. The reciprocal interference between system nodes considerably affects the path-delay and, so, the data-rate. The older interference-aware metrics tried to optimize these parameters: the DIAR ([10],[11]) is one of the interference-aware routing protocols for IEEE 802.11 networks and it is based on the *Network Allocator Vector Count* (NAVC). Thanks to the simulation results obtained in ([10],[11]), it has been discovered that the NAVC is not sensitive to the total number of nodes in the system. If the path with the lower NAVC is chosen, then it will correspond to the one with a lower delay and a lower interference ([12],[8]). A similar approach is made in [9], where the employed metric chooses the path with the lowest path delay, defined as the interval between the *Route REQuest* (RREQ) dispatch and the related *Route REPly* (RREP) reception. In [13], the chosen interference-aware metric is different from the previous one: the authors make the assumption that if there is a higher number of neighbour nodes, a higher probability of interference for a node will be observed; for this reason, through the adopted metric, called blocking metric *B(k)*, the routing protocol selects a certain number of paths, verifying that the sum of the coverage values of the nodes belonging to the single path is the lowest. It must be remembered that the coverage value of a node is the number of nodes that are directly covered from it. In [6], the authors propose the IBOR protocol, in which the employed metric makes of the interference level the parameter to take routing decision: the optimum route is that one minimized the interference effects. Starting from classic AODV protocol [5] and from IBOR protocol [6], a new metric, based on the concept of interference perceived by nodes on the paths of a route, has been proposed in this work. AODV is a reactive routing protocol based on distance vector algorithm. A key feature of the this protocol are the "*sequence numbers*", which provide to node method to assess what is update a particular route. Instead, IBOR is an interference-aware routing protocol for ad-hoc UWB wireless networks using a metric based on interference perceived by the nodes of the system similar to our protocol, however it differs substantially from it. Assuming that the main diversity is in the way of calculating the interference transmitted by the nodes, we can list in the following the most cared and improved issues:

- IBOR protocol does not consider the interference of a specific link between two nodes as basic metric, but the global interference perceived by the node. However, in this way, the metric includes interference areas that, although near the node, could not be affected the transmission;
- IBOR takes also into account of the minimum hop number in the final choice of the optimum route. It seems clear that this mechanism might badly affects the choice of the minimum interference route.
- Links refresh are delegated to AODV standard, therefore they occur only in the presence of breakage of links and not when there is a substantial variation of interference. In the presence of scenarios with mobility, having the routing tables updated on the basis of important variation of the perceived interference, it could lead to a better use of the minimum interference routes. channel behavior.

III. REFERENCE SCENARIO

In this section, some considerations about reference physical and MAC layers are made. In this work, we adopt as MAC layer the DCC-MAC model [2]. This protocol allows devices to perform multiple parallel transmissions, adapting communications on the basis of interference perceived by the same devices. To realize this, an opportune coding mechanism are used. DCC-MAC employs an UWB impulse radio physical layer based on TH-UWB IR as in ([3],[4]). Multi-user access is provided by pseudo-random *Time Hopping Sequences* (THS) that determine in which chip each user should transmit. Besides, due to the nonzero cross-correlation between time-hopping sequences, time-asynchronicity between sources and a multipath channel environment, TH-UWB is sensitive to strong interferers. Further details on this physical layer model can be found in ([3],[4]). A specific analysis about UWB network optimum planning is described in [14]. The authors drew the following conclusions: the optimum planning should not employ a power control and the sources should transmit with the maximum power; it is optimum in terms of throughput to allow the interfering sources to transmit concurrently on the condition that they are not in a well defined exclusion region around destinations and thus channel coding, and so data rate, must be adapted to the interference; on the other hand, interference into exclusion region must be contrasted. These issues are the basis of DCC-MAC. Interference at the receiver is more harmful when the impulses of a neighbor interfering collide with those of the source. Instead of inhibiting the sources into exclusion region, DCC-MAC uses a different strategy called interference mitigation. Interference mitigation allows to detect and erase interfering impulses having an energy higher than the signal received from the source: this scheme cancels the samples resulting from a collision with pulses of a strong interferer and replaces them by erasures (for example skipping them in the decoding process). Contrarily to others schemes as power control or exclusion mechanism, the interference mitigation does not require any coordination between nodes [2]: when a source must communicate, it transmits at the maximum power without considering others ingoing transmissions. The mechanisms provided by DCC-MAC, based on the management of THS, allow us to estimate the interference perceived on the reception of a packet. Further details on this protocol can be found in [2].



Routing Table				
Dest. Node	Next Hop	Sequence #	Interference	IsCorrect

a)

Neighbor List					
Node	Time Expire	Link Interference	Observation Window	Interference Count	Packet Count

b)

Figure 1. a) Routing table entry. b) Neighbor list.

IV. INTERFERENCE AWARE-BASED AD HOC ON DEMAND DISTANCE VECTOR (IA-AODV)

The proposed protocol has as basis the classic AODV protocol, of which inherits part of working operation and control packets, and the IBOR protocol, from which inherits the introduction of the interference concept in the selection of the optimum route. The novelty of the proposal is in the metric adopted for the choice of the optimal route from the source to the destination: it is not based on the hop number, as the classic AODV, or on the global interference perceived by nodes, as IBOR protocol, but on the interference affecting the link involved in the transmission. In order to realize this metric, it has been needed to modify some control packets: in particular, the *HopCount* field was replaced by *Interference* field in the RREP and RREQ packets. The modify was made also at the entry of the routing tables: the field *HopCount* was replaced by the *Interference* field, in which is stored the interference from the node to the destination, and *IsCorrect* field, a boolean variable that indicates the validity or less of links (see Figure 1.a). This last variable is needed because the interference on the link A-B could be different from that one on the link B-A, therefore we must be able to know if the value stored in the entry reefers to an interference perceived or transmitted by the node (this concept is better explained in the following). Further change has been made to the neighbor list updated by each node: it is added the *LinkInterference* field (see Figure 1.b) that stores the average interference perceived by the considered node in question in a given time window. Every node, therefore, stores the interference perceived on each wireless link that connects it to each of its neighbors. The computing of this value and its updating are shown in the following together with the various procedures adopted by the protocol. The other fields are to store the number of received packets in the observation window (*PacketCount*), the total amount of interference perceived in the window (*InterferenceCount*) and the expiry of the next observation time window (*ObservationWindow*).

A. Analytic Formulation

We suppose that a generic node A is receiving a packet, denoted by P_{BA}, from node B. During the reception of this packet, the node A detects an amount of interference (intended as interfering power in Watts) due to some packets transmitted by the nodes in its coverage range (and different from the node B). We indicate with *PI* the interference due to a generic packet interfering on the packet P_{BA}. This amount of interference is given by:

$$PI = P_{RX} \cdot CTC \tag{1}$$

where P_{RX} is the received interfering power, while *CTC* is the *Collision Time Coefficient* that is the fraction of the time needed to receive P_{BA} on which the interfering packet impacts. In particular, *CTC* is defined as:

$$CTC = \frac{WI}{TE_{P_{BA}} - TS_{P_{BA}}} \tag{2}$$

where TE_{PBA} and TS_{PBA} are respectively the start and end reception time for the P_{BA} packet, while *WI,* the interval during which the interfering packet impacts on the reception P_{BA}, is given by:

$$WI = \min(TE_{P_{BA}}, TE_{PI}) - \max(TS_{P_{BA}}, TS_{PI}) \tag{3}$$

where TS_{PI} and TE_{PI} are respectively the start and end reception time for the interfering packet. If we denote with PI_i the interference, perceived for the reception of the P_{BA} packet, due to the specific interfering packet *i*, then the total perceived interference for P_{BA} can be expressed as:

$$I_{P_{BA}} = \sum_{i=1}^{n} PI_i = \sum_{i=1}^{n} P_{RX_i} \cdot CTC_i \tag{4}$$

The node A monitors the wireless link condition for each neighbor computing the interference perceived on every link. Regarding its neighbor B, the node A will estimate the average interference perceived for the reception of each packet from B in a specific observation time window *WO*. At the end of this observation, the node A computes the average interference perceived on the link as:

$$I_{BA} = \frac{\sum_{j=1}^{m} I_{P_{BA_j}}}{m} \tag{5}$$

where $I_{P_{BA_j}}$ is the interference perceived by A at the reception of *j* packet from node B, while *m* is the number of packet received by A during the observation window. These information are available from neighbors list: *m* is stored in the *PacketCount* field, while the sum in the numerator is updated step by step and stored in the *InterferenceCount* field. The proposed protocol employs these interference values to find the minimum interference route on which to forward the packets. In particular, the interference from a source *S* to a destination *D* is given by:

$$Interference(S,D) = \sum_{\hat{ij} \in Path(S,D)} I_{\hat{ij}} \tag{6}$$

where $\hat{ij}$ link is a generic link belonging to the route from the source to the destination. The source will choose the most fresh route toward destination (managed with *sequence number* as in standard AODV) and with the lesser interference value, computed applying the (6). Every node will store the average interference perceived on each path, linking it to its neighbors, in the *LinkInterference* field of the neighbors list: this value is computed at the end of each observation window *WO* applying the (5).

The value stored in *LinkInterference* is updated only if the interference variation, respect to the stored value, is greater than a prefixed threshold α. Analytically, this can be expressed as:

$$\begin{cases} LinkInterference_k = LinkInterference_{k-1} & if \quad \dfrac{I_{\hat{ij}} - LinkInterference_{k-1}}{LinkInterference_{k-1}} < \alpha \\ LinkInterference_k = I_{\hat{ij}} & if \quad \dfrac{I_{\hat{ij}} - LinkInterference_{k-1}}{LinkInterference_{k-1}} \geq \alpha \end{cases} \tag{7}$$

In (8), $LinkInterference_{k-1}$ is the value stored at the end of (*k*-*1*)-th observation window. If the updating of the value stored in *LinkInterference* is required, then the node, performing the computing, informs its neighbor about interference variation (for example, referring to (7) the node *j* informs node *i* about link interference variation) using the unicast RRER mechanism contemplated by AODV protocol: this message is propagating to every node of the path toward destination *D* preceding the node discovering interference variation.

B. Route Discovery and Maintenance

When a node , indicated with originator, must communicate with another node of the network (called destination), it checks in its routing table if a valid *entry* toward that destination is present. In this case, the packets are sent toward the node indicated as *next hop* in the *entry* (likewise AODV standard). An *entry* is valid if it is fresh (this is provided by standard AODV procedure) and the *IsCorrect field* is set to true. Otherwise, that is no *entry* is present or it is invalid, the originator starts the route discovery procedure: a RREQ packet, in which the *Interference* field is set to zero (others fields are set following standard AODV procedure), are sent in flooding. When a node receives a RREQ, it adds to the *Interference* field the value stored in the *LinkInterference* field of the neighbor forwarding it the RREQ; therefore, if it has not an *entry* toward the originator, it creates a new *entry* inserting in the *Interference* field the new value stored in the RREQ and setting to false the *IsCorrect* field. This last step is needed because the interference stored in the RREQ is computed from originator toward this node and it could be different from the interference on the backward route: we must avoid that others RREQs use this wrong information about interference to reach the originator from the current node. If the *entry* is already present and its *IsCorrect* field is set to false, then the *Interference* field is updated only if the interference value stored in the RREQ is lesser than that one in the *entry* (*IsCorrect* field is not updated). In this way, the nodes, locally, make already a choice on the minimum interference route: if information updating about interference are made, the RREP will find fresh value and it will be forwarded automatically on the minimum interference route available until now. If the *IsCorrect* field is set to true, the *entry* is not modified in order to not wrongly change the information refereed to the correct direction toward originator. After these operations, the node must verify if it is the destination or if it has a valid route toward destination (we remember that the *IsCorrect* field must be set to true). If neither condition is satisfied, the node must forward the RREQ packet with the updated *Interference* field. Otherwise, the node must generate a RREP packet toward the originator through the nodes belonging to the route crossed by the RREQ (as in classic AODV). In particular, if the node is the destination, in the *Interference* field of the RREP is stored the value contained in the *LinkInterference* field relative to the neighbor forwarding it the RREQ; otherwise it must insert in the RREP the valued stored in the *Interference* field of the routing table *entry* relative to the destination at issue. After these operations, the RREP (with the remaining fields set in according to standard AODV) is forwarded to the previous hop of the route. Regarding the route maintenance, the proposed protocol maintains the AODV procedures based on the route freshness, on the link breakage and on the sending of RERR message. In addition to these procedures, a further mechanism was introduced to take into account of sensible interference variation on the links. For example, the node A computes at each observation window the average interference perceived on the path linking it to the node B applying the (5): if this interference is sensible varied respect to the previously stored value, that is in according to (7) an updating of *LinkInterference* field is required, then the node A sends a particular unicast RERR to the neighbor node involved in the link variation (in this case B). When the node B receives the RERR, it drops all entries in the routing table having the node A as next hop because the interference toward the destination stored in the *Interference* field of that *entry* is now not accurate. Then the node B informs, through the forwarding of an unicast RERR, all its precursor nodes involved in the interference variation of that route. The RERRs are backwards forwarded until all involved nodes know of the variation on the link B-A. This procedure allows us to have the information about the interference of various link always updated in the network.

Table I. Simulation Parameters.

Parameter	**Symbol**	**Value**
Transmission Power	Pt	0.280 *mW*
Nominal Bit Rate	br	18 *Mbps*
Bandwidth	Bw	5 *GHz*
Max speed	V_{MAX}	4 *m/s*
Packet Size	P_{size}	512 *Byte*
Interval between Packets	t_P	0.012 s
Node number	n	120, 140, 160,200
Max concurrent connection number.	Cmc	4, 8, 12, 20
Observation Time Window	WO	10 *s*

V. PERFORMANCE EVALUATION

The simulator, taken into account for our tests, is *Network Simulator 2* (ns-2) [15]. It is an object oriented simulator based on *C++* language with an *OTcl* interpreter interfacing the simulator with the end user. *OTcl* is an object oriented version of the script language *Tcl*. Further details can be found in [15]. Our protocol is tested considering the same reference scenarios: the node are randomly collocated on a $200m\times200m$ grid, on which they move in according to *Random Waypoint* mobility model with a speed variable in the range 1-4 *m/s*. Further simulation parameters are summarized in Table I. Performance evaluation has been carried out in terms of *Data Packet Delivery Ratio* (PDR), *Average End-To-End Delay* (AED) and *Normalized Routing Overhead* (NRO). In the following, some consideration on the threshold α (see section IV.A) are made and then simulation results are shown.

A. Analysis of α threshold

The choice of parameter α is a very important issue because it can affect link refresh mechanisms: a too small α could lead to frequent updating of the interference information that can cause a network traffic increment; on the other hand, a too high α should mean rare updating and so the information concerning interference could become obsolete. In order to find, in an experimental way, the value of α maximizing PDR (this parameter is preferred to others because our main goal is to reduce interference and so the packet loss) many simulations are carried out. Simulation results show that the optimum value for α is around 5% independently by node number and maximum concurrent connections. In particular, in Figure 2, the PDR vs. α trend is shown for a scenario with 4 and 8 maximum concurrent connection and, respectively, 120 nodes and 140 nodes. In the first case, we can see as the PDR increases until α =5%, it remains approximately constant and then it decrease for α>8%. In order to better proof our choice, the number of nodes and the maximum number of concurrent connections were increased respectively to 140 and 8. Also in this case the value of α, maximizing PDR, is around 5%. For this scenario, the advantages to choose α=5% is even more clear. On the basis of these results, the protocol performance evaluation, shown in the following, is made setting α parameter to 5%.

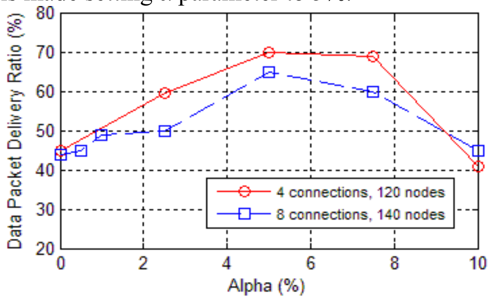


Figure 2. PDR vs. α in presence of 4 maximum concurrent connections, 120 nodes, and 8 maximum concurrent connections, 140 nodes.

B. Simulation Results Analysis

We start our analysis evaluating the performance indexes in function of node number with a fixed number of maximum concurrent connections, that is 12. In Figure 3.a, the PDR trend is shown: we can see as the data packet delivery ratio decreases to increase of nodes. In fact, a greater number of nodes in the network means a greater device density in a specific area and so a higher interference. This causes a regular performance degrading. However, our protocol provides performance better than others protocols: we have an improving of 10% respect to IBOR and 20% respect AODV. The best performance of the IA-AODV protocol is even more evident from the analysis of AED in Figure 3.b. With the increasing of the network node number, the average delay for IBOR and AODV protocols increases significantly, taking values very high in relation to the proposed protocol. The increase of delay is very influenced by the choice of route because the path at minimum interference reduces the number of retransmission of packet lost owing to interference and therefore it leads to a minor processing time for each node belonging to the same route. What is said about the PDR and AED, it is confirmed by the analysis of NRO shown in Figure 3.c. In fact, the augment of the interference, due to a greater node number, leads to an increase of the NRO. However, in this case, the three protocols present comparable performance: IA-AODV shows an overhead taking values between 6%-7%, whereas the other protocols show an overhead assuming values around 8% with a peak of 10% for AODV in presence of 200 nodes (in fact the links are lesser stable due to interference and so they break easily).

We shall now proceed to evaluate the performance of the proposed protocol varying the maximum number of concurrent connections fixing the total number of nodes in the network. We consider a scenario in which 120 nodes move on a grid with a maximum speed of 4 *m/s*.

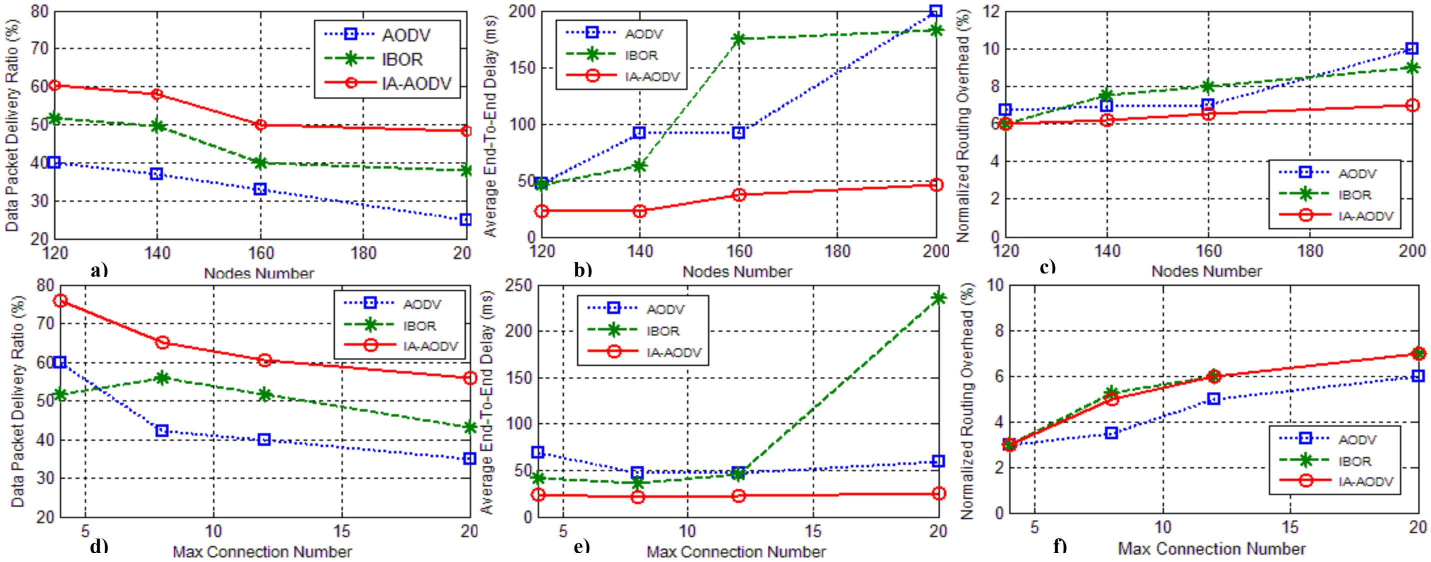


Figure 3. a) PDR vs. number node in presence of 12 maximum concurrent connections. b) AED vs. number node in presence of 12 maximum concurrent connections. c) NRO vs. number node in presence of 12 maximum concurrent connections. d) PDR vs. concurrent connection maximum number with 120 nodes. e) AED vs. concurrent connection maximum number with 120 nodes. f) NRO vs. concurrent connection maximum number with 120 nodes.

Observing the PDR curves depicted in Figure 3.d, we immediately note as IA-AODV shows a constant improvement respect AODV regardless of the number of connections. Compared with IBOR, this improvement, although decreasing, remains however around 10%. Figure 3.e shows the curves relative to AED. We can see as for IA-AODV the end to end delay is very little influenced by the number of concurrent connections, at least in the presence of 120 nodes. These considerations can be partially made also for AODV, while they cannot be made for IBOR because it shows an exponential increase of the delays. In Figure 3.f, the trend of NRO vs. maximum number of concurrent connections is show for all considered protocols. In this case, Our protocol pays slightly in terms of NRO: IA-AODV shows a NRO greater than 1-2 percentage points compared to AODV with a growing trend with increasing of the connection number. We have this trend because the presence of a lower node number (that is 120) leads to a lesser amount of global interference meaning also lesser link breakage and so lesser exchange of control messages for AODV. However, our protocol shows a NRO always lesser than 7%.

VI. CONCLUSIONS

In this work, a new routing protocol for UWB network, IA-AODV, based on the concept of interference, has been proposed. In particular, every node of the network estimates the interference on each path linking it to its neighbours: so these information are employed to discover the minimum interference routes. Our protocol is compared with the AODV and IBOR protocols in terms of PDR, AED and NRO: for this purpose a ns-2 simulator has been implemented. Simulation results show as IA-AODV performs better than others protocol both in terms of PDR and AED: e.g. for the PDR, we obtain an average improvement of 15% respect to AODV and around 10% respect IBOR. Generally, also NRO trend of IA-AODV is comparable (or better) to others protocols. Furthermore, we note that in presence of less dense scenarios (and so with a lesser global interference), IA-AODV has an overhead slightly higher than AODV protocol: however this gap is on the average around 1-2 % and so it is negligible respect the improving obtained in terms of PDR and AED.

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