Reducing Consecutive Errors in Industrial Wireless Networks Using Relaying and Packet Aggregation

Svetlana Girs[ξ], Elisabeth Uhlemann[ξ,‡] and Mats Björkman[ξ]
[ξ]Mälardalen University, Västerås, Sweden
[‡]Halmstad University, Halmstad, Sweden
svetlana.girs@mdh.se, elisabeth.uhlemann@ieee.org and mats.bjorkman@mdh.se

***Abstract*—Reliable and timely packet delivery in industrial wireless sensor networks is of the great importance. Wireless systems can bring significant cost and complexity reductions when replacing wires in existing systems, but will also introduce higher packet error rates. To overcome this problem, spatial diversity techniques, e.g. relaying, have proven successful. Even further gains can be reached by allowing the relay node to aggregate several different source packets into one. The schemes proposed in this paper are aiming to reduce not only the average packet error rates, but also the consecutive number of packet errors from a particular source. By allowing the relay node to keep track of the number source packet in error at the destination, it may prioritize the next packet from the source with the highest number of consecutive packet errors. Our scheme leads to a reduced number of consecutive packet errors, an important performance measure in industrial applications.**

I. INTRODUCTION

Providing timely and reliable real-time communication in industrial systems is crucial. Industrial wireless sensor network communication standards like e.g. WirelessHART [1], WIA-PA [2] or ISA100.11a [3] currently receive significant interest in the research community [4, 5]. Compared to wired solutions, wireless networks can bring lower costs and reduced installation and maintenance complexity. Moreover, wireless systems provide more flexibility and higher availability. However, higher packet error rates, resulting from signals travelling through wireless channels subject to shadowing and fading, should be taken into account. Thus, the aim of this work is to decrease the number of lost or corrupted packets by adopting a spatial diversity technique – relaying.

In relaying schemes, there are a number of intermediate nodes present in the system which, due to the wireless nature of the network, might overhear transmissions even if not addressed to them directly and help by forwarding these packets to their final destination. Relaying has previously proven to be successful for improving the achievable reliability for deadline-constrained data traffic in industrial networks, in particular when combined with packet aggregation; allowing the relay node to aggregate several different source packets into one, [6]. In this paper we extend the work in [6] by allowing the relay node to keep track of the number of times packets from each individual source were lost consecutively. The relay node may then prioritize the next packet from the source with the highest number of consecutive packet errors. Thus, the target is not only to decrease the average packet error rate per source, but also to reduce the number of consecutive errors encountered at the destination from each of the source nodes. The number of consecutive errors from each source is of particular importance, since many industrial applications can tolerate a specific number of consecutive errors (two consecutive errors can typically be tolerated, if the equipment is turned into a safe state), but have to be switched off if further errors are encountered.

II. SYSTEM MODEL

We study a network consisting of $N = 5$ sources (sensor nodes), sending their data to one destination (a central controller or a gateway), and one relay node located in-between, Fig. 1. Since a relay node consumes more power compared to sources, an actuator is typically set to perform relaying. The considered system can be seen as a segment of a whole network with the gateway located in the middle. Similarly, we consider only a subset of the whole time superframe. In the investigated scenario, the source nodes are first allowed to transmit one packet each. It is assumed that all sources have a data packet at the beginning of each superframe. The relay node is allowed to listen to source transmissions during these time slots. We consider a system where all source data has to be delivered before a common deadline (the end of the superframe) and assign three time slots in the superframe to the relay node (i.e., fewer slots than sources). We assume that within each time slot there is enough time for feedback, as in e.g. WirelessHART. Thus, overhearing the feedback packets (binary feedback, indicating if a packet was correctly received or not), the relay node knows which source packets are corrupted at the destination. Also, the relay node gets feedback from the destination about each relaying attempt. We assume that the feedback data is never lost or corrupted. The packet aggregation scheme implemented here is the one described in [6], where maximum three source data payloads can be aggregated into one longer packet, that packet still can be transmitted within the standard 10 ms long time slot.

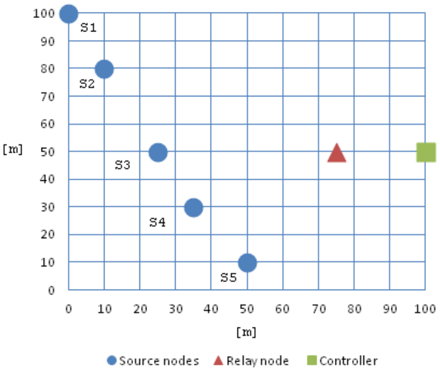

Fig. 1. Investigated node deployment

III. PROTOCOL DESIGN

Two general relay node behavior strategies are considered: "only Relaying" and "Relaying and Aggregation". These schemes are considered both with and without the strategy aiming to minimize two and three consecutive errors respectively. Given three relay slots in each superframe, the relay node constructs a queue of n packets to relay. The set of source packets considered, depends on the set of correctly received packets at the relay node and the set of packets lost at the destination. Given n, the strategy in the relay node is:

- If the relay has $n = 0$ source packets, it remains quiet.
- If the relay has $n = 1$ source packet, it simply relays this packet until a positive acknowledgment is received or until all relaying slots are used.
- If the relay has $n = 2$ different source packets, it first relays both packets according to the “only Relaying” scheme. If both packets still need to be retransmitted, one randomly chosen packet is repeated in the third slot. With the “Relaying and Aggregation” protocol, the relay node aggregates both packets into one and repeats this if needed.
- If the relay has $n = 3$ packets, the “only Relaying” scheme sends all three packets once, one in each slot, whereas the “Relaying and Aggregation” scheme concatenates all three packets into one and sends it (and repeats it, if needed).
- If the relay has $4 \leq n \leq N = 5$ source packets, it relays three randomly chosen packets with the “only Relaying” scheme. With “Relaying and Aggregation”, the relay includes all missing source packets at least once. If some packets need to be included more than once, these are chosen randomly.

The schemes adopted to decrease the frequency of two and three consecutive errors work similarly to the original protocols “only Relaying” and “Relaying and Aggregation”, except that the queue of packets to relay is organized so that packets from sources with one or two consecutive errors are prioritized. When also the relay retransmission of these higher priority packets, fails, they are relayed again immediately.

IV. RESULTS

In this section we present the simulation results from implementing the system model described in Section 2 and the protocols from Section 3 in Matlab. For each chosen scheme we simulate at least 300 000 superframes, or more, until we get at least 80 packet errors. The adopted channel model is a log-distance pathloss channel model [7] with additional frequency-flat block fading such that the fading gain remains constant during the transmission of one long packet. The time-varying fading process is assumed to follow Rayleigh distribution. We assume that IEEE 802.15.4-compliant transceivers are used and thus bit rate and transmitted signal power are taken from IEEE 802.15.4 standard. However, for simplicity, binary phase shift keying (BPSK) modulation is used in the simulator.

Simulation results are presented in table 1. The table shows the number of times two and three consecutive errors occurred for each source. It can be seen from the table that the proposed schemes prioritizing packets from sources having a packet error in the previous or the two previous consecutive superframes, decrease the number of occurrences of two and three consecutive errors. The gain is, however, much smaller with “Relaying and Aggregation” than with “only Relaying”. This observation can be explained by the fact that the aggregation schemes already enable all packets present at the relay node to be retransmitted. Thus, prioritizing packets from the sources with a higher number of consecutive errors only changes the order of the packets in the queue. The difference can therefore be noticed only when an aggregated packet is lost and retransmitted again, delaying the rest of the queue.

Furthermore, it can be noticed that the number of consecutive errors is still high. This can be explained by the fact that in a relatively high percentage of the cases when the destination needs a retransmission from the relay (e.g., 37.7% for source 1 and 11.8% for source 5, when considering two consecutive errors), the correct packet is absent at the relayer. At the same time, almost 100% of relaying attempts to avoid two and three consecutive errors are successful.

V. CONCLUSIONS AND FUTURE WORK

The main goal of the work presented in this paper is to decrease the number of consecutive packets in error at the destination from a particular source. The results show that the proposed method noticeably reduces the number of consecutive errors. At the same time, it can be seen that the relay node often does not hold a correct copy of the source packets needed at the destination, and consequently relaying cannot improve the quality of communication. Thus, the planned future work includes development of schemes increasing the number of source packets correctly received at the relay node. Also, aiming to improve the percentage of successful transmissions from the relay node, the planned future work includes design of more effective relaying schemes, possible with joint use of packet aggregation, forward-error-correction codes and packet combining.

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Table 1: Number of times 2 and 3 packets from each source are consecutively corrupted for the evaluated schemes

	Two consecutive errors					Three consecutive errors				
	1	2	3	4	5	1	2	3	4	5
No ARQ	44466	31522	17205	12983	10806	22779	13008	4782	3085	2254
Only ARQ	26449	15480	6230	4261	3415	9685	4110	1013	563	368
Only Relaying	9546	3298	504	307	282	1927	362	26	7	5
Only Relaying (prev. lost packets first)	9317	3139	463	276	229	1830	314	15	4	4
Relaying and Aggregation	9036	2951	393	223	192	1766	299	14	3	2
Relaying and Aggregation (prev. lost packets first)	9040	2950	392	223	192	1766	298	14	3	2