Poster Abstract
TAMOR a Thermal-Aware MultihOp Routing protocol for Ultrasonic Intra Body Area Networks

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I. Motivation

The rise in population aging witnesses the widespread attention towards the healthcare also by means of efficient and non invasive healthcare monitoring platforms. Intra Body Area Networks (I-BANs) are envisaged as the tool to implement this platform and will exploit the human body as the transmission medium, causing undesirable overheating of tissues and organs crossed by electromagnetic signals carrying information. To cope with this issue, at the physical level, it has been recently proposed to use ultrasonic waves for I-BAN applications [1–4] both to improve the transmission performance constrained in case of RF waves by the composition of the body (more than 65% composed of water, a mean through which electromagnetic waves scarcely propagate leading to very high attenuation) and for the purpose of avoiding temperature rise in proximity of organic tissues.

In parallel with this trend, thermal aware routing was proposed for On Body Area Networks where electromagnetic waves propagate on the surface of the body.

In this poster we try to combine the advantages of both approaches. In fact, on the one hand we propose to use ultrasonic waves at the physical level; on the other hand, at the network level, we introduce a thermal-aware routing protocol which allows to balance tissues overheating in IBAN.

Moreover, we have started an experimental activity to implement the thermal-aware routing protocol in a real testbed [2] along with the overall protocol stack needed for testing.

II. State of the art and contributions

In [5] for the first time, tissues overheating was addressed. In fact, the body thermoregulation allows to spread heat all over the body. However, if there is a heating peak, the abrupt increase of temperature can damage tissues and lead to cells necrosis. Accordingly in [5] it was proposed to consider temperature as a key metric for routing design. Similarly, in [6] the LTR mechanism is proposed to choose the routing path exhibiting the lowest temperature, as well as to delay packet transmissions so as to allow a decrease of the temperature along the chosen path. In [7] another routing approach requiring the exchange of a relevant overhead to dynamically assign path weights so as to take into account the ”heating level” on the different paths is presented. However, none of the above approaches takes into account the possibility to use ultrasonic waves, i.e. pressure waves which reduce remarkably the power needed to send messages. Also the need for differentiating the paths according to some performance metrics implies additional overhead which consequently leads again to tissues overheating. Another aspect which deserves attention in the context of IBANs is communication unreliability due to gestures and movements. In fact, due to human body movements, some nodes could become unavailable for a limited amount of time leading to frequent changes in the IBAN topology. In [8] for example a Link Likelihood Factor (LLF) is identified to represent the link connection probability for given link to be employed as a cost function during the initial phases to choose the path towards the sink. However, again this approach, while trying to overcome the limitations of link unreliability, causes an excessive overhead to exchange LLF messages.

The TAMOR protocol presented in this poster tries to combine all the advantages of the discussed solutions in the following ways:

- TAMOR employs ultrasonic waves in the range 6-10 MHz which has been shown [3] to represent the recommended operating range to allow coverage range around tens of cms compatible with the use of intra body sensor devices distributed along the body in a reasonably-not too capillary way.
- TAMOR uses a cost function which takes into account statistics on the number of correctly received packets to weight the different neighbor nodes when choosing the next hop in the forwarding process. This function implicitly accounts for both reliability due to topology variation and overheating of tissues.
- The feasibility of supporting TAMOR in a real IBAN has been preliminarily tested by means of a real testbed developed using USRPs [9] and including Olympus V326-SU ultrasonic transducers, Mini-Circuits Pulse Amplifier (PA) ZPUL-30P, and Low Noise Amplifiers (LNA) ZFL-1000LN+ to filter and amplify the received signal. The transmission channel is obtained by considering real organic tissues embedded inside a ballistic gel, mimicking human body features.

III. The TAMOR protocol

In the design of the TAMOR protocol we will exploit a cost function which can be derived by each node individually and without requiring to exchange any additional packet with neighbor nodes. In particular, each node, upon deciding to

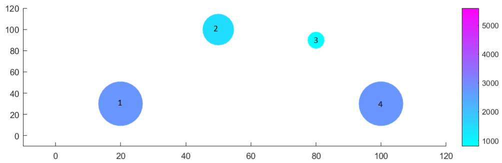

Fig. 1. Temperature level at the different nodes.

TABLE I
AVERAGE LOSS ON THE 3 AVAILABLE PATHS

Average Loss	P_2	P_3
	3.03%	4.3%

which, among its neighbor nodes, forwarding the packet, chooses the neighbor which guarantees to decrease the cost function. More specifically the cost function for each neighbor node will take into account both the temperature level in the area around that neighbor and the link status towards that node. Accordingly, a parameter α is considered which counts the number of packets sent to the specific neighbor that were not confirmed through piggybacking. By using the parameter α we indeed employ a conservative approach since the lack of confirmation could be simply due to a delay or missing traffic in the opposite direction. However, by so doing, it is possible to reduce the risk to incur into overheating at specific network nodes. Concerning topology changes due to body movements, observe however that the temporal scale of such changes is significantly larger than the packet transmission time so allowing to foresee that routing topology updates will be performed on bursts of packets. A simplified pseudocode of TAMOR behavior is reported in Figure 1.

We have preliminarily implemented the TAMOR protocol on our GnuRadio Platform employing USRP. Some tests have been performed on a 4 nodes topology where 3 paths are available from a transmitter node N_1 to a receiver node N_4. The paths are labeled as $P_1 = \{N_1, N_4\}$, $P_2 = \{N_1, N_2, N_4\}$ and $P_3 = \{N_1, N_3, N_2, N_4\}$. Preliminary results shown in Figure 1 and Table III show that the TAMOR approach is reasonable and can be effective in achieving equalization of temperature values. In fact, observe that, apart for the temperature level in the surroundings of the transmitter and receiver nodes (N_1 and N_4), the temperature level along the 2 paths (P_2 and P_3) are almost the same. Concerning the average losses experienced along the paths, note that due to the increase in temperature, the use of multihop transmission can be proficuous in avoiding tissues overheating and thus losses. At the best of our knowledge this is the first attempt to realize an Intra Body Area Network where multihop routing is experimentally tested.

IV. WORK IN PROGRESS

In order to further evaluate our initial intuition on the use of ultrasonic multihop transmission in IBANs, we are comparing different functions for the choice of the policy to select the forwarding node. We will accordingly estimate the impact in terms of achived throughput, temperature level and reliability of the system. Finally we will fully implement the protocol in GNURadio and make it available opensource for experimentation to the research community.

Algorithm 1 TAMOR: simplified sketch of the algorithm.

At each network node I

j: neighbor identifier in the set $\mathcal{N}$ of the neighbor nodes of node I;

T_j: temperature estimated at the neighbor node j;

l_j: link quality indicator for the link from node I to node j;

$\alpha_j = f(T_j, l_j)$: number of packets sent by I to the node j that were not confirmed;

$f(\cdot,\cdot)$: function representing how the number of packets not confirmed depends on the temperature estimated at the neighbor node as well as on the link quality indicator;

$m = f(T_1, l_1)$ Initialized cost value;

$Relayer = 1$ Candidate node for relaying;

for $j = 2 : \mathcal{N}$ **do**

  if $m > f(T_j, l_j)$ **then**

    $m = f(T_j, l_j)$ Cost value updated;

    $Relayer = j$; Candidate node for relaying updated

  end if

end for

forward_message_to($Relayer$);

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