Power-aware Routing in Wireless Packet Networks

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Abstract

A key characteristic of Personal Area Networks (PAN) (e.g., Bluetooth technology) is the premium placed on reducing the power consumption of device computation and communication. In such an environment some devices may be more capable of communicating with others simply because of their power capability (i.e., reserve). We propose a "power-aware" routing protocol capable of routing packets in a PAN based on power related optimization (viz. minimize and balanced) and device behavior (viz. greedy and social) criteria. Our proposal differs from previous work on power consumption in packet wireless networks which typically aims at reducing the overall device usage and energy consumption.

Introduction

Communication networks comprised of personal devices in close proximity of each other such as cellular phones, PDAs, notebooks, pagers, etc., are usually referred to as *Personal Area Networks* (PANs). Emerging short-range wireless standards such as *Bluetooth* [1] or IEEE 802.15 [2] will allow personal devices in a PAN to communicate with each other via wireless links. A key characteristic of this emerging technology is the premium placed on reducing power consumption. This is generally achieved by allowing personal devices to operate in low power consumption modes, and sleep modes during periods when no packets are destined for reception at a particular device. Even with such power conscious technology, additional techniques will be required to make the introduction of PAN technology efficient in operation. Power conservation for personal area networks devices motivates this position paper.

In this case of PAN it is anticipated that the same RF technology will be incorporated into a diverse set of host devices in various forms (e.g., add-ons to PC-card or fully integrated solution for a cellular phone). With the same radio incorporated into different devices they will all share the same characteristics regarding coverage, power consumption, signaling and communication protocols. However, even if the radios are the same and consume similar amounts of power, the battery life depends on the overall device design and its primary usage. For example, a radio attached to a PDA device will have more power restrictions compared with the same radio embedded in a desktop PC.

In this position paper we propose a power conservation protocol that treats wireless networked devices differently by accommodating their power reserves. The proposed research work focuses on the development of a routing protocol to economically forward packets between a source and destination node in a PAN in a *power-aware* manner. This work is different from previous work in the area of power consumption in wireless networks which mainly aim to reduce usage (and thus energy consumption).

In general, more power is consumed during the transmission of packets than the reception of packets or during "listening" periods. In addition, transmission to a distant device at higher power levels may consume a disproportionate amount of power in comparison to transmission to a node in closer proximity. These observations motivate our protocol which focuses on the interplay between power control and allowing "in-between" nodes (intermediate nodes) to relay packet transmissions in order to minimize power transmission among nodes in a PAN.

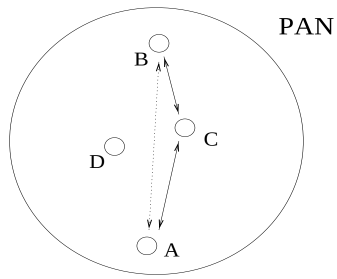

Figure 1: *Example of Power Aware Forwarding*

Figure 1 illustrates an ad-hoc PAN where all nodes are located within transmission range of each other. In Figure 1 nodes A and B use node C to relay (i.e., forward) packets to each other. This approach is in contrast to traditional routing protocols for packet radio networks where typically packets are transmitted directly between pairs of nodes located within direct transmission range.

Routing Policy: Minimize or Balance Power

There are a number of important protocol choices to be made when developing power-aware routing protocols for personal and wide area networking. The selection of the best transmission/routing policy that achieves the desired power consumption is an important area of study. Clearly, choosing a route that minimizes the total transmission power necessary to reach the destination would be a good candidate policy. Minimizing the total transmission power, however, has the drawback that it can potentially consume the battery of a forwarding node jeopardizing its operation and future performance and usage. Based on this observation, we consider that maximizing the battery lifetime of the nodes should be a primary priority. A routing policy addressing the latter objective could be one that balances the power in the network, or favors forwarding nodes with generous power reserves first. In a non-uniform network, where not all the nodes consume power identically, and have equal power reserves, these two optimization objectives are not necessarily equivalent. Choosing a route, which balances the power, may not be necessarily the route with minimum transmission power requirements and, as a result, inefficient use of power resources could take place.

There is also a time dimension to this problem. Lets say that node A is currently using node C to forward its packets because it balances the power in the network. We also assume that this route is power-wise inefficient (e.g., there exists a next hop D which minimizes transmission power). Depending on topology changes and the behavior of the traffic in the future, unit C may run out of power but node D may still have power. In the scenarion node A uses the power of node C inefficiently assuming that it is beneficial to the overall system performace. This is not the case, however, in this scenario. We observe that there is no absolute winner between the policies of minimizing and balancing power unless the behavior of the system is known in advance. When this is not the case, we may opt to accommodate both objectives simultaneously as best we can.

Device Behavior: Greedy or Social

A natural enhancement to these routing policies is to allow them to react according to the time-varying battery reserves of nodes in the PAN. A node with a generous power reserves should be able to forward traffic if another node requests it. We call this operational mode *social mode*. In contrast, when the battery level of a node falls below a certain threshold, the node may refuse to forward any more traffic. We call this operational mode *greedy mode*. Social and greedy modes also impact the behavior of source nodes. A source node with low power reserves will search for the nearest node to forward its packets without worrying about minimizing/balancing power policies. The battery level threshold dividing social and greedy modes depends of the specific device the radio is attached to.

Power Cost Function

An appropriate cost function must be taken into account that assigns a cost to each possible route in a way that reflects the optimization objectives.

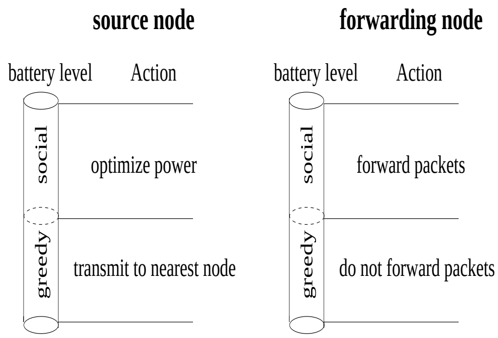

Figure 2: *Operation Mode vs. Battery Level*

The cost function should capture both the cost of transmission for each node enroute and how much each node "prices" its battery power while forwarding packets. If the packet travelling along route k needs N transmissions to reach its destination then the cost of each alternative route R_k is defined as follow:

$$R_k = \sum_{i=0}^{N} P_i f(B_i) \quad (1)$$

The first factor in Equation 1, P_i, is the transmission power for node i. The transmission power should take into account the attenuation of the medium and the sensitivity of the receiver node. The path loss is typically described by a function $1/d^{\alpha}$, where d is the distance from the transmitter and α is a function of the distance and the type of environment (e.g., outdoor, office building, etc.). The second factor in Equation 1, $f(B_i)$, models how much each node prices its battery power at the time of transmission. Different types of nodes may have different functions $f(B_i)$. Issues such as current battery level, total storage capacity, type of battery, etc., can be translated into meaningful parameters in the system. For example a node using non-rechargeable batteries will price its battery power at a significant premium over a PC connected to the main power supply infrastructure.

Routing: Route-redirect Protocol

In our proposal routing is based on a basic operation called *route-redirect*. The motivation behind this concept is that nodes with generous power reserves should support more of the routing operation (i.e., route discovery and packet forwarding processes). Nodes insert transmitted power and battery cost parameters in the header of each transmitted packet as well as the total cost of the route. The route-redirect technique assumes that nodes can listen to (i.e., overhear) transmissions. Figure 3 shows a simple illustrated example of the route-redirect operation for a PAN with three nodes. These nodes are within transmission range and all operate in social mode in this scenario. The protocol operates in the following manner when transmitting packets between nodes X and Z in the example scenarios:

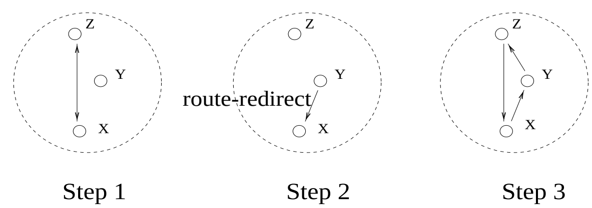

Figure 3: *Route-Redirect Operation*

Step 1: Let us assume that nodes X and Z are unaware of presence of a third node (node Y). When node X communicate with node Z, node X has no choice but to transmit the packets directly to node Z. In the case that node X is not aware of its distance from node Z, node X may "search" for node Z by transmitting at full power and then adjusting the transmission power once node Z replies with a packet of its own.

Step 2: Because node Y is capable of"overhearing packets" from both X and Z nodes, node Y can estimate the power attenuation with respect to both nodes. If node Y computes the new route X $\rightarrow$ Y $\rightarrow$ Z and it offers a lower cost than the route X $\rightarrow$ Z then node Y sends a route-redirect message to node X as is illustrated in Figure 3. In this example the route Z $\rightarrow$ Y $\rightarrow$ X is more costly than route Z $\rightarrow$ X.

Step 3: After receiving the route-redirect message from node Y, node X transmits packets for node Z first to node Y which then forwards these packets to node Z.

We are currently investigating alternatives for addressing the issue of multiple route-redirect messages received by a node from several "in-between" nodes. One approach is to let the transmitting node collect all route-redirect messages for a period of time and then let this node choose which of the advertised routes offers the lowest total cost. An alternative approach is to let potential forwarding nodes advertise lower cost routes first. In this way a potential forwarding node overhearing a route-redirect advertisement offering a route with lower cost will refrain from transmitting its own route-redirect request resulting in less control traffic in the network.

The route-redirect approach discovers routes on the fly making it suitable for highly dynamic mobile scenarios where computing the routes in advance could be costly in terms of signaling overhead. When one of the forwarding nodes in one route moves away or is powered down, the previous node in the route is responsible for reestablishing the route. This task can be achieved by transmitting with full power in order to "find" the destination node, and then let "in-between" nodes optimize the route again as described earlier.

An important aspect of our research is to extend the protocol to operate in the "wide area". Limiting the routing protocol to "within range" scenarios is restrictive for some topologies. In the case of wide-area networking, most routing protocols for packet radio networks can be categorized as being *before-demand* [6] or *on-demand* protocols [4], or some combination thereof [5]. Before-demand protocols compute and maintain routes even if nodes are not actively transmitting packets. In contrast, on-demand protocols compute routes only when necessary. One common property of before-demand and on-demand protocols is that they search for new routes by transmitting with full power. Figure 4 illustrates the tradeoff between the transmission power and the convergence of the protocol (e.g., delay, number of hops, etc.).

Clearly searching for routes using more power reduces searching time and the number of hops involved in reaching a specific node. Transmitting with high power, however, reduces the overall capacity in the network, resulting in higher collision probabilities and reduced frequency and/or spatial reuse. On the other hand, reducing the

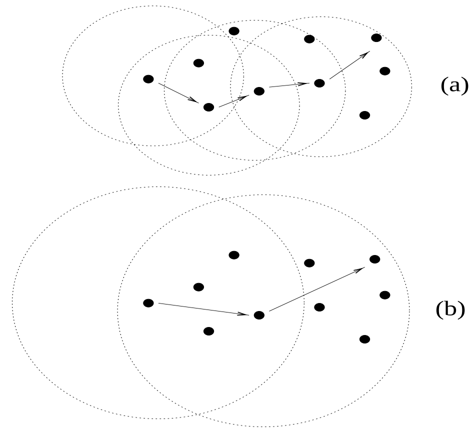

Figure 4: *Search Range Tradeoff*

transmission range increases throughput at the expense of increasing the number of nodes required to reach the destination and thus the end-to-end delays. There is, however, a limitation on the lower bound of power transmission that depends on the average density of nodes in the network. If a node searches with insufficient power to reach another node then the searching protocol will not work.

In our framework a node operating in greedy mode would like to forward its packets to the nearest node operating in a social mode sometimes only centimeters away. This situation is not compatible with the wide area routing protocol operation. Because of this limitation we propose to separate wide area routing with local power optimization. However, we use a wide area routing protocol to find unknown routes at high power. Following that, we use the route-redirect protocol to optimize routes locally. As a result, we keep the signaling overhead of the searching aspects of the routing protocol low while reducing the transmission power in order to find the route with minimum power cost.

Conclusion

In this position paper we have proposed a "power-aware" routing protocol capable of routing packets in a personal area network based on power related optimization and device behavior criteria. We are currently implementing the protocol within the NS2 simulator to further study the schemes utility operating in personal and wide area networks. The results from this phase of the work will be the subject of a future publication.

References

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