Mobile Offloading in Wireless Ad Hoc Networks

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***Abstract*— This paper proposes a strategy for mobile offloading that takes into account how "tight" the nodes are to deliver a packet successfully towards a destination within a given deadline. By using the proposed tightness concept, three strategies are defined for each step of the game: the bidding strategy, the budget-and-fine set up strategy, and the request-for-bids set up strategy.**

I. Nomenclature and Definitions

When the *source access point* announces its *request for bids* (RFB), it announces its budget B_0, along with a fine F_0 to be paid in case the data packet is not delivered to the destination AP after traversing a *maximum number* H_0 of hops (i.e., this is the "timeout" announced by the source AP). Let hc_i denote the number of hops (or "hop count") of the *shortest path* (in terms of number of hops) computed from node i to the destination AP. Also, let p_i denote the number of hops traversed by a packet from the source AP to a given node i in the network.

A key metric in our proposal is the definition of a "tightness function" Δ_i for a node i in the network, i.e., Δ_i measures how "tight" a node i is with respect to making the deadline H_0 imposed by the source AP. In other words, given the timeout H_0 announced by the source AP, and the number p_u of hops already traversed by the data packet all the way to node i's upstream node u (the one who will issue an RFB), Δ_i measures the "surplus" or "deficit" (in number of hops) that node i possess with respect to the timeout H_0 *if the data packet were forwarded through its shortest path to the destination AP*, given by

$$\Delta_i = (H_0 - p_u - 1) - hc_i, \quad \forall i \in \mathcal{N}(u), \tag{1}$$

where $\mathcal{N}(u)$ is the set of nodes who are able to overhear the RFB from node u, i.e., the neighbors of node u. Therefore, if $\Delta_i < 0$, node i cannot deliver the data packet within the deadline (even if the data packet follows node i's shortest path to the destination AP). On the other hand, if $\Delta_i = 0$, node i needs *exactly* the number of hops contained in its shortest path to the destinatio AP in order to make the deadline. This is a "tight" situation for node i, since it relies on the unpredicted outcome of other downstream auctions for the packet to arrive within the deadline. Finally, if $\Delta_i > 0$, node i has a higher chance to deliver the data packet within the deadline because the packet may even deviate from its shortest path to the destination AP, but it has a "surplus" of hops before the deadline is up. Based on such definitions, we next specify three strategies needed for operation in the mobile data offloanding challenge: the *bidding strategy*, the *budget-and-fine setup strategy*, and the *request-for-bids strategy*.

II. The Bidding Strategy

The bidding strategy defines how the value of the bid is set once an RFB is overheard from an upstream node u. For that, we first need to determine the set $\mathcal{N}(u)$ of neighbors of the upstream node u. This set contains *our competitors* in the upcoming auction, and it can be easily found because all nodes have complete knowledge of the network topology. For each node $i \in \mathcal{N}(u)$, we compute Δ_i according to Eq. (1). Based on the values of Δ_i, we create a subset $\mathcal{S}(u) \subseteq \mathcal{N}(u)$ that contains all nodes in $\mathcal{N}(u)$ such that $\Delta_i \geq 0$, i.e., the set $\mathcal{S}(u)$ contains all nodes that are actually able to deliver the packet within the deadline and, therefore, they are the ones most likely to win the auction announced by node u (our actual competitors). Observe that, we are assuming that node u will usually prefer not to pay a fine.

Given $\mathcal{S}(u)$, we want to estimate how competitive we are in terms of packet delivery from the point of view of node u. It is reasonable to expect that the likelihood of successfully delivering a packet will play a key role in any decision making by any node. Therefore, we choose to find out how competitive we are by using our "tightness function." Specifically, we compute how "tight" we are with respect to the *average tightness* $\overline{\Delta}$ of nodes in $\mathcal{S}(u)$, defined as

$$\begin{aligned} \overline{\Delta} &= \frac{1}{|\mathcal{S}(u)|} \sum_{i \in \mathcal{S}(u)} (H_0 - p_u - 1) - hc_i \\ &= (H_0 - p_u - 1) - \overline{hc}, \end{aligned} \tag{2}$$

where $|\mathcal{S}(u)|$ is the cardinality of $\mathcal{S}(u)$, and $\overline{hc}$ is the average optimal hop count over all $i \in \mathcal{S}(u)$, i.e., the average *shortest path* to the destination AP computed for each node $i \in \mathcal{S}(u)$. Once the average tightness $\overline{\Delta}$ is found, we can compute our *relative tightness* c_n with respect to $\overline{\Delta}$ by

$$c_n = \frac{\Delta_n}{\overline{\Delta}} = \frac{(H_0 - p_u - 1) - hc_n}{(H_0 - p_u - 1) - \overline{hc}}, \tag{3}$$

where the subscript n is used to identify ourselves. It is important to mention that the above computation will only happen if our tightness function is such that $\Delta_n > 0$ and $|\mathcal{S}(u)| > 0$. Otherwise, we have specific rules for making our bid (explained later).

Observe that, if $c_n < 1$ and $\Delta_n > 0$, our competitors are better positioned than us (on average, with respect to a surplus of hop counts). Therefore, there is a high chance that they become more aggressive to win the bidding, since they may feel that they can deliver the packet in time. At the same time, since $c_n < 1$, it means that we are running a higher risk on not having the packet delivered to its final destination, compared to others. Therefore, we may want to set a higher bid (closer to the budget B_u) because the risk should not be worth it to take. In case $c_n \approx 1$, we have similar conditions than other competitors and, therefore, we should try to win the auction with a lower bid compared to previous case. However, if $c_n > 1$, it means that we are better positioned than the average of our competitors. Therefore, we should strive to win the bid by offering a very attractive price (closer to the fine F_u).

In additon to c_n, another important metric to take into account is how Δ_n (the value of our tightness function) compares to the *biggest* value of Δ_i for $i \in \mathcal{S}(u)$. This is because, if $\Delta_n > \max_{i \in \mathcal{S}(u)} \Delta_i = \Delta_{\max}$, it means that we are the best choice for the upstream node u in terms of a positive surplus of hop counts towards destination. Therefore, we should strive to win the auction by becoming as aggressive as possible in our bid (i.e., to set lower values for the bid to make sure we win the auction). Otherwise, if $\Delta_n << \Delta_{\max}$, we should have very low expectations to win the auction and, therefore, we should not make dramatic changes in our bid for different values of c_n. Based on that, we define the parameter a_n that compares our tightness value with the best tightness value in $\mathcal{S}(u)$, i.e.,

$$a_n = \frac{\Delta_n}{\Delta_{\max}}. \tag{4}$$

Given the values of the budget B_u and the fine F_u announced by the upstream node u, and since $F_u \leq B_u$ (according to auction rules), our offered bid $O(c_n)$, will be given by a *logistic function* of the form

$$O(c_n) = (B_u - F_u)\left[1 - \frac{1}{1 + e^{-a_n(c_n - 1)}}\right] + F_u, \tag{5}$$

where $F_u \leq O(c_n) \leq B_u$, i.e., we opt for never making a bid less than the established fine F_u. As it can be seen, the logistic function is centered on $c_n = 1$, and the steepness of the curve is controlled by a_n.

Finally, if $\Delta_n < 0$, we discourage the upstream node from choosing us by setting our bid equal to the budget B_u. Likewise, if there is no competition, i.e., we are the only node reachable by the upstream node, we set our bid to the maximum value B_u, and if $\Delta_n = 0$, it means that we are very "tight" and, therefore, we should set our bid to B_u (high risk).

III. Budget-and-Fine Set Up Strategy

Once an auction is won, the strategy to set the budget B_n and fine F_n to be announced on an RFB is based on a fixed rule. Given that the upstream node paid us an amount equal to our winner offer O^*, the budget B_n and fine F_n will be set to

$$B_n = 0.6 \times O^* \quad \text{and} \quad F_n = 0.9 \times B_n, \tag{6}$$

where the value of 60% and 90% were estimated to be reasonable values that can afford, from time to time, some loss not so high (according to auction rules).

IV. Request-for-Bids Set Up Strategy

In order to determine who wins our RFB, we want to consider both the offered price op_i and the *relative tightness* c_i of each neighbor i around us (except for the upstream node from whom we received the packet). Based on those values, we want to determine the best neighbor to foward our packet to. The maximum offered price we can receive is our own budget B_n, and the maximum relative tightness $c_{\max}$ is related to the neighbor with the highest tightness value Δ_i. In our strategy, we value a high relative tightness more than a good offered price, since we want to guarantee packet delivery as much as possible. Therefore, we need to define a *preference function* $P_n(c_i, op_i)$ that translates our preference towards the received bids. Hence, the lowest preference would be given to the node that has $c_i = 0$ and $op_i = B_n$, i.e., $P_n(0, B_n) = 0$. On the hand, the highest preference would be given to the one where $c_i = c_{\max}$ and $op_i = 0$ (for free). Other interesting cases are $P_n(0,0)$, where it reflects the case when the node is "tight," but it has offered "free forward", and the case $P_n(B_n, c_{\max})$ where the node has offered the maximum bid, but it is the best node. If $P_n(0,0) = k_1$ and $P_n(B_n, c_{\max}) = k_2$, we may set $k_2 > k_1 > 0$ to reflect our tendency to favor packet delivery as opposed to earn money. The absolute values k_1 and k_2 are not important, but their relative magnitudes should translate our relative preference between those scenarios (adjustable according to the game). The equation of a *plane* that intersects those points can be obtained so that the *preference function* $P_n(c_i, op_i)$ is finally defined as

$$P_n(op_i, c_i) = k_1 - \left(\frac{k_1}{B_n}\right) op_i + \left(\frac{k_2}{c_{\max}}\right) c_i \tag{7}$$

Figure 1 depicts the case for the hypotetical values $B_n = 20$, $c_{\max} = 3$, and $k_1 = 2$, and $k_2 = 3$.

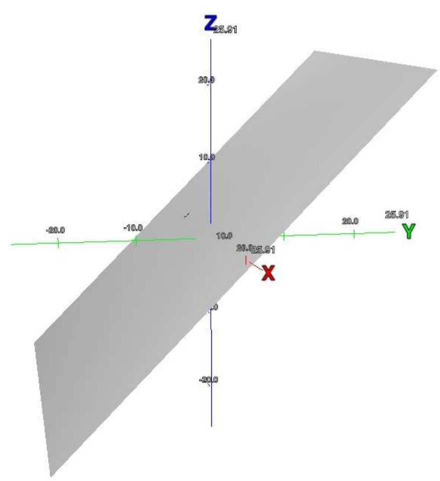

Fig. 1. Example of preference function for the values $B_n = 20$, $c_{\max} = 3$, $k_1 = 2$, and $k_2 = 3$