Dijkstra-Based Higher Capacity Route Selection Algorithm Using Bounded Length and State Change for Automobiles

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Abstract— **In general, automobiles travel from the origin to the destination using a shortest route. However, the shortest route may not be a highest wireless connection-capacity route, because of availability of wireless services (base station and access points etc.) along the route. To the best of our knowledge, currently no algorithm exists for selecting a route that maximizes wireless connection-capacity, while keeping route length shortest and close to shortest. In this paper, we propose two modified version of Dijkstra route selection algorithms: one for selecting a maximum connection capacity shortest route, and the other is for discovering higher wireless connection-capacity routes; the length of the route could be larger than a shortest route, but no larger than predetermined bound. The second proposed algorithm exploits the state change of the intersection to broaden the search range of possible routes. Results from our extensive simulation for a Manhattan-street type grid network with the heterogeneous IEEE 802.11a wireless access, show that for a 50% increase in route length and 15 Access Points (APs), the proposed algorithm can increases wireless connection-capacity by 35.67% and 31.27% compared to the shortest and random route selection algorithms, respectively.**

Keywords- Dijkstra's algorithm; shortest route; higher wireless connection-capacity; tolerable length increase

I. INTRODUCTION

Advancement of wireless technology has enabled automobile users to access the Internet services anytime from many roads. To provide stable and high speed coverage over larger area, service providers emphasize on integrating various wireless access technologies, such as, 3G cellular networks, WiMAX, Wifi, and WLAN, etc. Due to variation of wireless connection speed provided by various wireless technologies at different roads, when automobiles travel between two points, different routes will have different wireless connection capacities. Therefore, when searching for a route from an origin to a destination, it is important to consider connection capacity as well as the length of the route. Over a decade, the Global Position System (GPS) assisting automobile drives to select shortest or near-shortest route to their destination. But, GPS selected route may not have best wireless connection-capacity (which is also not expected from it). Besides, currently no algorithm exists for selecting the route with the maximum wireless connection-capacity when there are multiple shortest routes. In this paper, we consider the following problem: Given a route length - which is equal to or longer than the length of a shortest route - how to find a route such that it's total wireless connection-capacity is maximized. We define the wireless connection-capacity of a path as the amount of data that can be uploaded or downloaded while traveling on the route at a designated driving speed. Note that this problem is different from the packet routing problem that routes the packet from the source to the destination subject to the required quality of service (QoS), resource utilization, or a combination of both [1]. In addition, it is also different from the routing in wireless ad hoc networks. In latter, each node has mobility and it is necessary to handle potential route failure for continuous connectivity [2-3]. To the best of our knowledge, the problem that we consider here has only been addressed in [4].

We implement two algorithms for selecting driving route from a origin point to a destination point such that the total wireless connection-capacity is maximized, while keeping driving distance minimum and close to minimum. It is assumed that a road map with driving distances and a road map with wireless connection-capacities are available. If multiple shortest routes exist between two points, the first algorithm finds a shortest route that has the maximum wireless connection-capacity. The second algorithm finds a route whose length is smaller than or equal to a given length (which is longer than the length of the shortest route) but the total wireless connection-capacity is higher than that of the shortest route. Both algorithms are modification to the Dijkstra's shortest route selection algorithm. The proposed second algorithm avoids exhaustive search for keeping polynomial time-complexity at the cost of finding a route that is not optimal. However, simulation results show that it outperforms the Dijkstra's algorithm based random route selection in homogeneous and heterogeneous Manhattan-street type grid networks.

II. Preliminaries

First we define a road network as a weighted graph. Every node of the graph is an intersection of two or more road segments. The weight of a road segment is its physical distance or time it takes to drive from one end to the other end of the road segment Formally,

Definition 1 (Road Networks): A *road network RN(I,R)* is defined as a weighted undirected graph with a set of n_I intersections $I = \{I_1, I_2, ..., I_{n_I}\}$, and a set of n_R road segments $R = \{R_1, R_2, ..., R_{n_R}\}$. A road segment R_j connects two distinct intersections I_k and I_l and have a positive weight ω_j, which is either the physical distance between the two intersections or the driving time from one end to the other end of the road segment.

It is assumed that from some or all of the road segments wireless connections are available to mobile terminals. For convenience of discussions let us define a wireless access network as a collection of access points

Definition 2 (Wireless Access Network): A *wireless access network WN(AP,L)* consists of a set n_{AP} access points $AP = \{AP_1, AP_2, ..., AP_{n_{AP}}\}$, each of which are connected to the Internet via a broadband wired link. Thus, the bandwidth available to a user's connection is the bandwidth of the wireless link of the access point that is providing the access to the Internet. An access point AP_i is positioned at location $L_i = < x_i, y_i, z_i >$, where x_i, y_i, and z_i are three coordinates of the AP_i and thus, $L = \{L_1, L_2, ..., L_{n_{AP}}\}$.

Definition 3 (Wireless Capacity Graph): For a road network *RN(I,R)*, the *wireless capacity graph WCG(I,D)* is defined as an weighted undirected graph with a set I of n_I intersections of the road network, and a set of n_R wireless connection capacity $D = \{D_1, D_2, ..., D_{n_R}\}$; for every road segment R_j, there is a wireless connection capacity D_j.

The concepts we have defined can be illustrated by a Manhattan-street model shown in Fig. 1. A small circle represents an intersection of two, three, or four road segments. A black circle represents an intersection where an access point is set up to provide wireless Internet service. The number beside a road segment denotes the transmission rate provided by the access points. The coverage area of an access point is assumed to be a circle with a diameter with the length of two

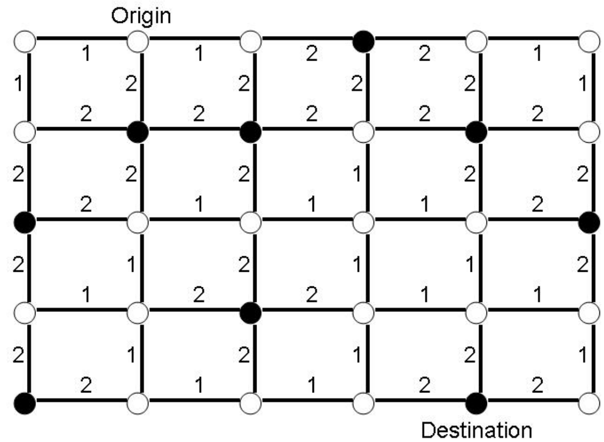

Fig. 1. Manhattan street model.

road segments. The transmission rate of the road segments connected to the access point is twice of that of the other road segments in the coverage area. Note that when a road segment is covered by multiple access points, the transmission rate is equal to the maximum value of the transmission rates provided by multiple access points because we assume that each mobile terminal is equipped with only one transceiver.

III. Maximum Connection-Capacity Shortest Route Selection Algorithm

We propose a modification to the standard Dijkstra's We propose a modification to the standard Dijkstra's algorithm that will find a maximum wireless connection-capacity route among all shortest routes. This algorithm takes *RN(I,R)* and *WCG(I,D)* as a input and produces a maximum wireless connection-capacity shortest route. The modification is quite simple: if two or more intermediate intersections have same shortest distance from the origin, then select the one with most connection-capacity for the next iteration step. The part of the algorithm that is new and / or different from the original Dijkstra's algorithm is shown in bold letters.

- Initialization steps:
  - Set distance value to zero and **connection-capacity to zero** for the Origin intersection.
  - Set distance value to infinity and **connection-capacity to zero** for all other intersections.
  - Mark all intersections as unvisited.
  - Mark Origin as current.
- Iterative steps:
  - Repeat
    - *For* all unvisited neighbors of the current intersection *do*
      1. Calculate their distances and **connection-capacities** (from the Origin intersection).
      2. If the present distance of a neighbor is less than the previously recorded distance, set

its distance to the newly computed distance and **connection-capacity** to the newly computed **connection-capacity**.

3. If the present distance of a neighbor is equal to the previously recorded distance and newly computed **connection-capacity** is greater than previously recorded **connection-capacity**, set its **connection-capacity** to the newly computed **connection-capacity**.

- ✧ Mark the current intersection *visited.*
- ✧ **Let *I'* be the set of unvisited intersection with the smallest distance (from the Origin). From *I'*, select an intersection that has maximum connection-capacity as the next "current node". (If more than one of intersections in *I'* have maximum connection-capacity, select one of them randomly.)**

➢ Until the Destination is "current intersection"

IV. Bounded Length Higher Connection-Capacity Route Selection Algorithm

The algorithm presented in the previous section selects a shortest route that has most connection-capacity among all the shortest routes. But a limitation of the algorithm is that it cannot find a path whose length is longer than a shortest route, but will have higher connection-capacity than all shortest routes. In this section, we present an algorithm that will find a higher capacity route whose length is no more than a predetermined length. This algorithm can be utilized, for instance, to find a higher capacity route whose length is no more than, say, twice the length of the shortest route.

The algorithm works in two steps. First, length of shortest route to each intersection from the Origin is computed and saved. Let the distance of an intersection I_i from the Origin be SP_i and that of the Destination be SP. Let the length of the desired route be less than or equal to GL. Let $DL = GL - SP$, be the difference between GL and SP.

We use GL to remove some intersections that cannot be part of the desired driving route; to be more specific, if an intersection's distance is greater than GL, it is removed to get a smaller road network. For the proposed algorithm, an intersection can have three states: unvisited, visited, and final. An intersection is marked unvisited during initialization of the algorithm, then it may alternate between visited and unvisited states; an intersection is marked final when no further improvement is possible; for instance the Origin is marked final during initialization, since we cannot come back to this intersection without creating a loop. Once an intersection marked 'final' its state will not change after it.

We compute DL_i, sum of DL and SP_i for each intersection I_i, and use it to limit length of routes to the intersection. After a visit to an intersection I_i, it is marked visited as in the Dijkstra's algorithm. But while visiting an intersection, distances and connection capacities of all neighbors marked unvisited and visited are calculated, and based on these values, as discussed later, the state of an intersection can be changed from visited to unvisited. For an intersection I_i marked visited, let d_e and d_c be existing and computed distances, and let cc_e and cc_c be existing and computed connection-capacities. We need to consider the following cases:

- Case 1: $d_c = d_e \le DL_i$ and $cc_c > cc_e$. Change the marking of the intersection I_i from visited to unvisited, and record cc_c as capacity of I_i.
- Case 2: $DL_i > d_c > d_e$, $cc_c > cc_e$, and forms no loop. Change the marking of the intersection I_i from visited to unvisited, and record d_c and cc_c as distance and capacity of I_i.
- Case 3: $d_c > DL_i > d_e$. Do not change marking.

During each iteration, one intersection is selected for possible updating distance and capacities of its neighbors. The algorithm terminated when there is no unvisited intersection for further exploration. The part of the algorithm that is new and / or different from the original Dijkstra's algorithm is shown in bold letters.

- Initialization steps:
  - ➢ **Use the Dijkstra's algorithm to calculate SP_i.**
  - ➢ Set distance value to zero and **connection-capacity to zero** for the Origin intersection.
  - ➢ Set distance value to infinity and **connection-capacity to zero** for all other intersections.
  - ➢ Mark all intersections as unvisited.
  - ➢ Mark Origin as current.
- Iterative steps:
  - ➢ Repeat
    - ✧ *For* each (unvisited or visited) neighbor I_i of the current intersection *do*

      1. Calculate their distances and **connection-capacities** (from the Origin intersection).
      2. **IF (($d_c = d_e \le DL_i$) and ($cc_c > cc_e$)), and forms no loop, THEN change the marking of the intersection I_i from visited to unvisited, and record cc_c as capacity of I_i.**

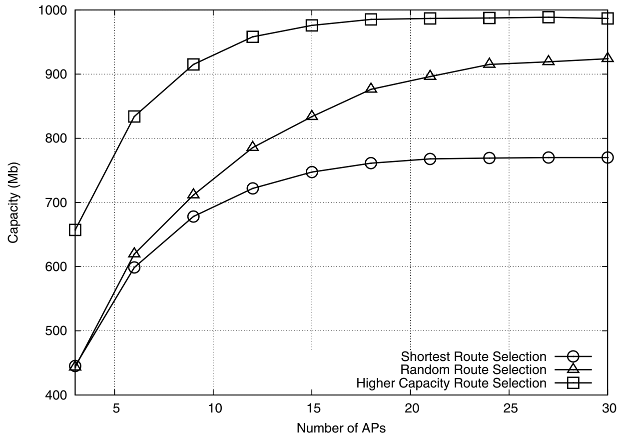

Fig. 2. Capacity performance of the homogeneous IEEE 802.11b wireless access with the route length ratio of 1.5.

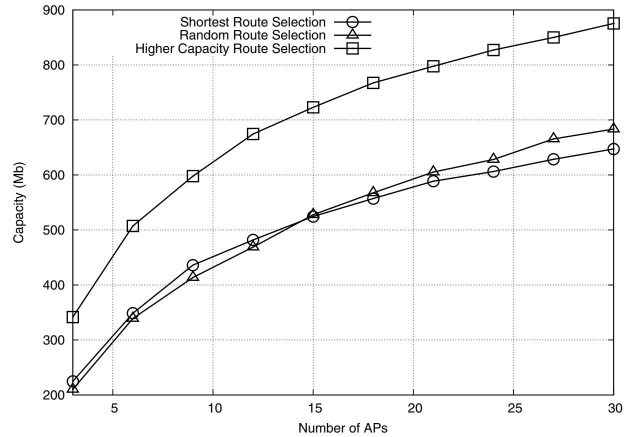

Fig. 3. Capacity performance of the heterogeneous IEEE 802.11b wireless access with the route length ratio of 1.5.

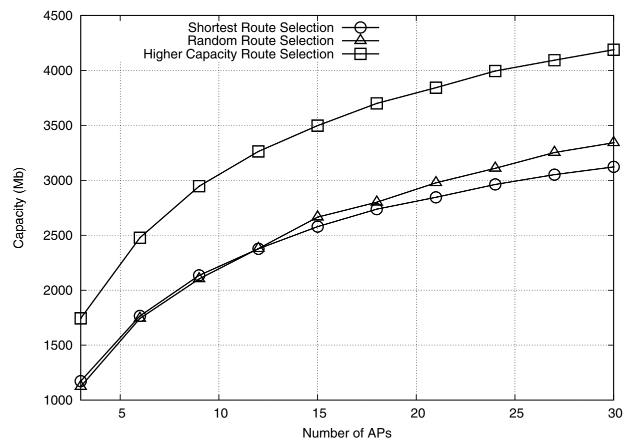

Fig. 4. Capacity performance of the heterogeneous IEEE 802.11a wireless access with the route length ratio of 1.5.

3. **IF (($DL_i > d_c > d_e$) and ($cc_c > cc_e$), and forms no loop, THEN change the marking of the intersection I_i from visited to unvisited, and record d_c and cc_c as distance and capacity of I_i.**

- **IF distance of the current intersection I_i is DL_i, THEN mark the current intersection *final***, ELSE mark the current intersection *visited*.
- **Let *I'* be the set of unvisited intersections whose distances (from the Origin) are smallest. From *I'*, select an intersection that has maximum connection-capacity as the next "current node". (If more than one of intersections in *I'* have maximum connection-capacity, select one of them randomly.)**

➢ **Until *I'* is empty.**

V. Performance Evaluations

We simulated a 5x6 Manhattan-street model for evaluation of performance of the proposed algorithm. It is assumed that a road segment is 100m long. The driving speed of the automobile is 36 km/h. Thus, traveling one road segment takes 10sec. The automobiles travel through streets with three different types of wireless access: homogeneous IEEE 802.11b, heterogeneous IEEE 802.11b, and heterogeneous IEEE 802.11a. In the homogeneous IEEE 802.11b, the data rates of all access points are fixed to 11 Mb/s. In the heterogeneous IEEE 802.11b, each access point can support four data rates: 1, 2, 5.5, and 11 Mb/s and randomly selects one of them for transmissions. In the heterogeneous IEEE 802.11a, each access point can support eight data rates: 6, 9, 12, 18, 24, 36, 48, and 54 Mb/s and randomly selects one of them for transmissions. The origin and the destination are fixed for all network scenarios. In each network scenario, access points are randomly placed at intersections. For eliminating potential bias, we simulated 1000 network-instances.

Figure 2, 3, and 4 show the number of APs versus wireless connection-capacity of the homogeneous IEEE 802.11b and the heterogeneous IEEE 802.11b and 802.11a wireless access with the route length ratio of 1.5. From plots in Fig. 2, 3, and 4, we can observe that the proposed higher capacity route selection outperforms the random and shortest route selections. When traveling through the streets with the homogeneous IEEE 802.11b wireless access, and the number of APs is 15, the proposed higher capacity route selection algorithm obtains average increases of 30.59% and 17.06% of the wireless connection-capacity compared to the shortest and random route selection, respectively. In addition, when the wireless access is heterogeneous IEEE 802.11b, and the number of APs is 15, the improvements of the proposed higher capacity route selection are 37.81% and 37.01% compared to the shortest and random route selection, respectively. Another observation from plots in Fig. 2, 3, and 4 is that at a fixed wireless connection-capacity, the proposed higher capacity route selection reduces the number of APs compared to the random route selection. When traveling through the streets with the homogeneous IEEE 802.11b wireless access, and the total wireless connection-capacity is about 915 Mb, the proposed higher capacity route

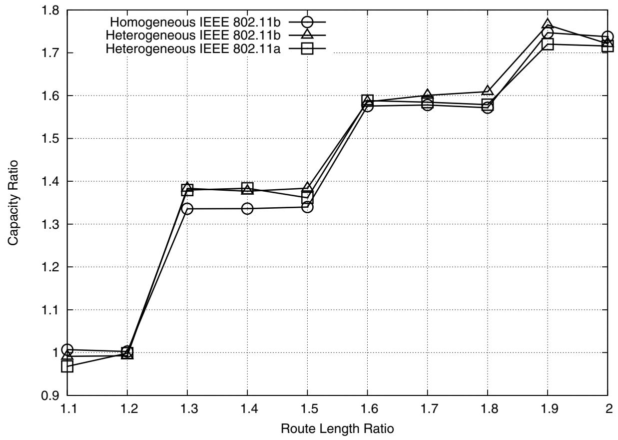

Fig. 5. Capacity performance of the higher capacity route selection compared to the shortest route selection with 10 APs.

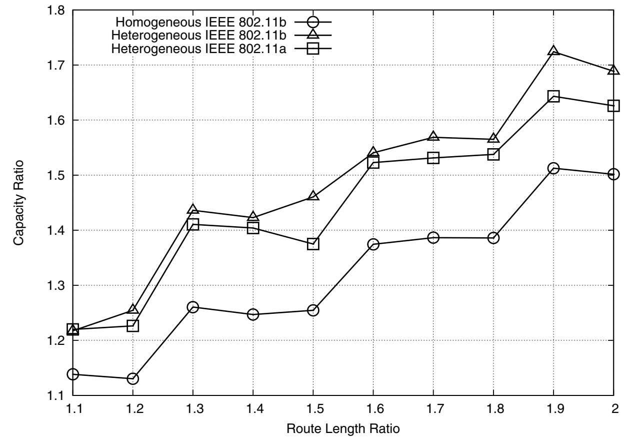

Fig. 6. Capacity performance of the higher capacity route selection compared to the random route selection with 10 APs.

selection reduces the number of APs by 62.5% compared to the random route selection. Besides, when the wireless access is heterogeneous IEEE 802.11b, and the total wireless connection-capacity is about 683 Mb, the improvement of the proposed higher capacity route selection is 56.67% compared to the random route selection.

Figure 5 shows plots of the route length ratio versus the ratio of the capacity of the higher capacity route selection to that of the shortest route selection with 10 APs. The route length ratio equals to the ratio of the length-bound to the length of the shortest route. From plots in Fig. 5, we can observe that the proposed higher capacity route selection achieves nearly the same capacity ratio in different wireless access models. Besides, at a lower route length ratio, the proposed higher capacity route selection achieves the capacity ratio of a higher route length ratio. For example, when traveling through the streets with the homogeneous IEEE 802.11b wireless access, the proposed higher route selection achieves the capacity ratio of 1.34 for the route length ratio of 1.5 when the route length ratio is 1.3. Figure 6 shows plots of the route length ratio versus the ratio of the capacity of the higher capacity route selection to that of the random route selection with 10 APs. The random route selection is implemented based on the Dijkstra' algorithm and selects a route with higher capacity but the length is bounded. From plots in Fig. 6, we can observe that the proposed higher capacity route selection increases the wireless connection-capacity compared to the random route selection in three different wireless access models. This is because in the higher capacity route selection, all possible qualified routes are compared to each other, and the one with the highest capacity is selected. Besides, the proposed higher capacity route selection achieves higher capacity ratio in the heterogeneous IEEE 802.11b and IEEE 802.11a than in the homogeneous IEEE 802.11b. The reason is that in heterogeneous wireless access models, the random route selection has the possibility to select the route composed of the segments whose data rates are lower than 5.5 or 11 Mb/s provided in homogeneous wireless access model. Another observation from plots in Fig. 6 is that the capacity ratio of the heterogeneous IEEE 802.11b is greater than that of the heterogeneous IEEE 802.11a. The reason is that for the heterogeneous IEEE 802.11b and 802.11a, the ratio of the maximum transmission rate to the minimum transmission rate are 11 (11/1) and 9 (54/6), respectively. Note that although the capacity ratios shown in Fig. 5 and 6 are the results of the 5x6 Manhattan-street model, for a nearly square but larger Manhattan-street model, the capacity ratios are the same as that shown in Fig. 5 and 6. Besides, from some parts of plots in Fig. 5 and 6, we can observe that when the route length ratio increases, the capacity ratio decreases. This is because at each specified route length ratio, we use different sets of network scenarios for simulations.

VI. CONCLUSIONS

In order to get more communications capacity while on the road, we propose a Dijkstra-based heuristic algorithm, which finds higher capacity route within a specific length. The proposed algorithm significantly improves the capacity compared to the shortest route, and its time complexity is comparable to that of the Dijkstra-based shortest route selection algorithm. Extensive simulation results have shown that when traveling through the streets with the heterogeneous IEEE 802.11a wireless access, the total wireless connection-capacity is 3341 Mb, and the route length ratio is 1.5, compared to the random route selection, the proposed higher capacity route selection on an average decreases the number of APs by 56.67%.

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