Evaluation of Wireless Multi-hop Localization Game for Entertainment Computing

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Abstract—We have developed a wireless multi-hop localization game, i.e., a war game, based on a classical field game. The players use mobile game consoles with ad-hoc networking capability and play the game on a field. The fundamental concept underlying a wireless multi-hop localization game is that players on a team establish an ad-hoc network to estimate their positions and then compete for positioning accuracy with other teams by using a multi-hop localization technique. Simulation revealed that velocity and obstruction position were the key parameters in playing the war game. The simulation results demonstrated that the proposed game made a good use of the ad-hoc networking capability.

I. INTRODUCTION

Wireless multi-hop networking has provided the flexibility needed to construct various types of sensor networks. The emerging products for sensor networks, such as Zigbee [1], use multi-hop networking to construct networks. The technique of multi-hop networking has been discussed in the IETF by the Mobile Ad-hoc Network Working Group [2], and mobile game consoles with ad-hoc networking capability have been produced by companies such as Nintendo [3] and Sony Computer Entertainment (SCE) [4]. The networking capability plays an important role for multiple players to join a game together. Since the ad-hoc networking technique is independent of the infrastructure network, it is easy for a player to join a game through a wireless network. Therefore, the ad-hoc networking capability is expected to boost the potentials of games using networking capability. However, the games released thus far use the ad-hoc networking capability only for joining the game.

We have developed two wireless multi-hop localization games with ad-hoc networking capability. The proposed games, a war game and a tag game, are based on classical field games. Players using mobile game consoles with ad-hoc networking capability move around a field. The game uses wireless multi-hop localization to estimate node positions. The players on each team jointly establish an ad-hoc network to estimate their positions and compete for positioning accuracy with the other team. We used a previously developed multi-hop localization technique called ROULA [13]. We used simulation to evaluate the multi-hop localization games and analyze their characteristics. We found that node velocity and obstruction position are important parameters in the war game.

The results revealed that the proposed games worked well as games made good use of the ad-hoc networking capability.

The focus of this paper is presenting the primitive ideas for multi-hop localization games with ad-hoc networking capability. The concept behind a multi-hop localization game is presented. A wireless multi-hop localization game is evaluated how well localization-based games with ad-hoc networking capability perform in a simulation. An ad-hoc network is constructed to perform a multi-hop localization, and the positioning accuracy obtained by using the multi-hop localization is then used to compete for winning a game. Simulation results help to know fundamental parameters affecting the game operations.

Due to the space limitations, we present the results for only the war game in this paper. The results for the tag game will be reported in a future article.

We next describe the multi-hop localization and the use of networking in entertainment computing. The localization technique of ROULA is reviewed in Section III. Section IV describes our wireless multi-hop localization game, and our evaluation of them is discussed in Section V. Section VI concludes the paper with a brief summary and mentions future work.

II. LOCALIZATION AND NETWORKING

A. Multi-hop localization

Multi-hop localization techniques have been discussed for wireless multi-hop networks such as sensor and ad-hoc networks. The motivation of developing multi-hop localization is to know the node position in the wireless multi-hop networks by using a small fraction of anchor nodes. An anchor node is one for which the position is known in advance through such means as Global Positioning System (GPS) positioning. Location information is used not only to bundle the source of sensing information in an sensor networks, but also to improve the performances of the ad-hoc network [5].

Much research has been conducted on how to estimate node positions in wireless multi-hop networks [6], [8]–[13]. We previously developed the optimized link state routing-based localization (ROULA) [13]. ROULA does not require the use of extra ranging devices, such as ultra sound devices, for each node to estimate its position. We thus use ROULA in our
proposed game to enable the nodes to estimate their positions. ROULA is described in Section III.

B. Networking in entertainment computing

A number of game consoles have been developed for the entertainment computing market. There are two basic types: home game consoles and mobile game consoles. The Nintendo Entertainment System™ (“Famicom” in Japan) is the iconic home game console and was introduced in 1983 by Nintendo [3]. A user plays the games by using a hand-held controller specific to the console. Although Famicom does not have networking capability, it supports multiple players. Two users can play games using two controllers connected by cables to the console.

The mobile game consoles have been developed with ad-hoc networking capability, such as Nintendo DS™ in 2004 by Nintendo [3] and Play Station Portable (PSP)™ in 2004 by SCE [4]. Both the Nintendo DS and PSP have ad-hoc networking capability, so they can connect with other consoles even without a wireless base station. Multiple users can play a game, such as golf or auto racing, by using this ad-hoc networking capability.

However, the existing games for mobile consoles use ad-hoc networking capability only for connecting game players without an infrastructure network. They thus do not fully utilize the ad-hoc networking capabilities of consoles.

III. Optimized Link State Routing-based Localization

A. Overview of ROULA

In our two wireless multi-hop localization games, the players use ROULA [13] to estimate their positions. We briefly review the ROULA technique. A more detailed description of ROULA and its performance are described elsewhere [13].

Figure 1 presents a conceptual representation of ROULA in a non-convex network topology. ROULA is independent of anchor nodes and can determine the correct node positions in a non-convex network topology. In addition, ROULA is compatible with the optimized link state routing (OLSR) network protocol [14] and uses the inherent distance characteristic of multipoint relay (MPR) nodes.

The basic idea behind ROULA is that each node matches regular triangles that form exactly convex curves and grows them into global coordinates by merging overlapping regular triangles iteratively. ROULA is independent of anchor nodes and can determine the correct node positions in a non-convex network topology. A non-convex network topology can occur when nodes cannot be deployed in some areas because of obstructions, for example, buildings or natural features such as trees or mountains. To find convex curves, nodes in ROULA search for nodes that are arranged into regular triangles.

Nodes in ROULA are assumed to use the OLSR protocol in the network layer. They localize MPR nodes as their 1-hop nodes without any modification of the MPR selection. Flooding hello packets and the computational task of MPR selection can be integrated by using the underlying network layer processes.

We assume that nodes are deployed in a two-dimensional plane. Routing protocol operations are assumed to be done without requiring additional time.

IV. Wireless Multi-hop Localization Game

A. Overview

The fundamental concept underlying a wireless multi-hop localization game is that players on a team establish an ad-hoc network to estimate their positions and then compete for positioning accuracy with the other team by using a multi-hop localization technique. The players use mobile game consoles, called “nodes”, with ad-hoc networking capability and play the game on a field.

Figure 2 presents the principle state transition diagram for a multi-hop localization game. Each node is either a “dead” or an “alive” node. The initial state is alive. Nodes periodically send hello packets and update their positions by multi-hop localization. The condition for transition to a dead node is based on positioning accuracy. The more accurate the positioning by obtained a node, the lower the probability of it transitioning to a dead node. When an alive node meets the condition to transition to a dead node, it makes the transition.
Random waypoint constrained to

characteristics of human strategies to win a game as random

motions.

collaborate to accurately estimating node positions to improve

positioning accuracy [13]. Therefore, the nodes on a team can

ROULA can estimate node positions by using the number of 1-

to other nodes, it can specify the number of 1-hop nodes.

The two objectives of using the ad-hoc networking capa-

bility are to connect nodes within a limited communications

range and to estimate node positions. The nodes cannot communicate with the nodes

on the other team.

We used the positioning error as the metric to determine

whether a node transitions to a dead node. The positioning

error, $e_i$, is normalized by the communication range, $R$:

$$
e_i = \sqrt{(\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2} \div R, \quad i = 1...N,$$

where $N$ is the total number of nodes, $(x_i, y_i)$ represents the

true position of node $i$, and $(\hat{x}_i, \hat{y}_i)$ is the estimated position.

The true position can be obtained by using such means as GPS

and A-GPS [7]. When a node cannot estimate its own position,

it is assigned a positioning error of 100%. A node transitions

to a dead node depending on its positioning error. Node $i$

transitions to a dead node in accordance with Algorithm 1.

Nodes periodically flood hello packets. When a node senses a

hello packet, it receives it if it has come from a node on the

same team. Otherwise, the node drops the packet and decides

whether to transition to the dead node on the basis of the

positioning errors (lines 5–8 of Algorithm 1). The $\mathcal{U}(a, b)$

represents a random variable with a uniform distribution in the

interval $[a, b]$. If the node has the same positioning error, it

transitions to the dead node with a probability of 50%

(line 5 of Algorithm 1). Otherwise, the node transitions to the
dead node if it has a greater positioning error. Once the node

transitions to the dead node, it stops moving and receiving

packets for localization. If all the nodes on a team transition to

the dead nodes, the other team is declared the winner.

Algorithm 1: When node $i$ senses hello packet of node $j$

1: if node $i$ is on same team as node $j$ then
2: receive packet.
3: else
4: drop packet.
5: if $e_i = e_j$ & & $\mathcal{U}(0, 100) \leq 50$ then
6: transition to dead node.
7: else if $e_i > e_j$ then
8: transition to dead node.

The condition for finalizing the game is different from a game

goal.

The two objectives of using the ad-hoc networking capa-

bility are to connect nodes within a limited communications

range and to estimate node positions. Once a node connects
to other nodes, it can specify the number of 1-hop nodes.

ROULA can estimate node positions by using the number of 1-
hop nodes, and the greater the number of nodes, the better the

positioning accuracy [13]. Therefore, the nodes on a team can

collaborate to accurately estimating node positions to improve

their chances of winning. Here, we simplified the mobility

characteristics of human strategies to win a game as random

motions.

B. War game

Let $N_{tm}$ denote the number of teams and $N_n$ denote the

number of nodes required to finalize the war game. Each team

has an equal number, $N_n$, of players. The goal of the war

game is for $N_n$ alive nodes on a team to reach the enemy

line. $N_{tm}, N_n$, and $N_{n}$ can be varied. $N_{tm}$ was consistently

set to 2 and $N_n$ was set to 1 for the war game discussed here.

Let us consider the case of $N_n = 80$. Figure 3 shows

example snapshots of war game for time steps 500 and 1000.

The field is divided in half, and each team initially occupies

one of the two areas. Each team has the same number of nodes.

The nodes for team 1 are represented by circles, and those for

team 2 are represented by triangles. The arrows in Fig. 3(a)

indicate the locations of the enemy lines, which were set 10

[m] from the back end of each team’s area. The mobility of
each node was modeled as a random waypoint constrained to

advance toward the enemy line. The velocity of each node was
determined by using a random variable with an exponential
distribution, $\mathcal{E}(v)$, with a mean of $v$. If a node reaches the

enemy line, its team is declared the winner. The nodes on

each team periodically run multi-hop localization to estimate

their positions. The nodes cannot communicate with the nodes

on the other team.

We used the positioning error as the metric to determine

whether a node transitions to a dead node. The positioning

error, $e_i$, is normalized by the communication range, $R$:

$$
e_i = \sqrt{(\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2} \div R, \quad i = 1...N,$$

where $N$ is the total number of nodes, $(x_i, y_i)$ represents the

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(line 5 of Algorithm 1). Otherwise, the node transitions to the
dead node if it has a greater positioning error. Once the node
transitions to the dead node, it stops moving and receiving
packets for localization. If all the nodes on a team transition to
the dead nodes, the other team is declared the winner.

V. Evaluation

A. Simulation settings

The simulation environment we used was a discrete event
simulation environment, OMNeT++ [15] with the Mobility
Framework [16]. The simulation trials were conducted 30
w times with random seeds, and the results were averaged.
Table I lists the simulation parameters for the war game.

B. Impact of number of nodes

Figure 3 shows snapshots of the war game at time steps of
500 and 1000 for 160 nodes. We set the mean node velocity
$v$ of all nodes to 1 [m/step]. A cross on a node represents a
dead node. As we can see from Fig. 3(a), the nodes proceeded

![Figure 3. Snapshots of war games for time steps (a) 500 and (b) 1000 (N=160, $v_{x1,y2}=(1,1)$). Nodes for team 1 are represented by circles, and those for team 2 are represented by triangles. A cross on a node represents a dead node. Arrows indicate locations of enemy lines.](image-url)
toward the enemy lines. As time went by, the nodes got closer to the enemy lines, and more and more nodes died, as seen in Fig. 3(b).

Figure 4 plots the positioning error, localization rate, and number of alive nodes against the time step when each team (T) had 120 nodes. The variance in the positioning error increased as the number of alive nodes decreased, which is consistent with the finding that that number of nodes contributes to positioning accuracy in multi-hop localization [13]. As time went by, the number of nodes that could participate in localization decreased. Hence, the variance in positioning accuracy increased. We defined the localization rate as the percentage of nodes that could localize themselves out of all alive nodes. The number of alive nodes decreased over time. A small number of nodes makes it difficult to estimate node positions using multi-hop localization. Therefore, the localization rate decreased as the number of nodes decreased. The number of alive nodes on both teams remained approximately the same over time. This is because all the nodes had the same velocity and used the same strategy to proceed to the enemy lines.

Figure 5 showed the results for 160 nodes. Compared with the results for 120 nodes, the localization rate was better, confirming that the number of nodes contributed to the localization rate.

Table II lists the number of wins by team for 30 trials with the different parameter settings. The row for scenario A in Table II shows that the number of wins for teams 1 and 2 for 120 and 160 nodes, was 16 and 14, and 15 and 15, respectively. The number of nodes did not significantly affect the number of wins.

Although the results presented here were for basic scenarios, we observed that the multi-hop localization game using ROULA worked well as a game with the ad-hoc networking capability.

C. Impact of velocity

We evaluated the impact of velocity by varying the velocities of the nodes on each team. Figure 6 plots the positioning error, localization rate, and number of alive nodes when the velocities of nodes on team 1 were 1 and those of team 2 were 2. The localization rate of team 2 was slightly lower than that of team 1. This is because the nodes on team 2 were more spread out due to their moving more quickly, making it more difficult to estimate node positions using multi-hop localization.

### Table II

<table>
<thead>
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<th>Scenario</th>
<th>N</th>
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<th>Team 2</th>
</tr>
</thead>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>N</td>
<td></td>
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<tr>
<td>120</td>
<td>16</td>
<td>14</td>
<td></td>
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<tr>
<td>160</td>
<td>15</td>
<td>15</td>
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<tr>
<td>Scenario B:</td>
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<td></td>
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</tr>
<tr>
<td>v_{T1,T2}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{1,2}</td>
<td>12</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>{1,4}</td>
<td>9</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Scenario C:</td>
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<td></td>
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<td>y coord. of obst.</td>
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<td>1</td>
</tr>
<tr>
<td>250</td>
<td>15</td>
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</table>

Although the results presented here were for basic scenarios, we observed that the multi-hop localization game using ROULA worked well as a game with the ad-hoc networking capability.
However, the goal of the war game is to reach the enemy line. The row for scenario B in Table II shows the number of wins for teams 1 and 2 as for velocities of 1 and 2 [m/step]. Although the localization rate of team 2 was slightly lower than that of team 1, team 2 had more wins. This is because the condition for finalizing the war game is reaching the enemy line, the team with the higher average node velocity had the greater number of wins.

Figure 7 plots the positioning error, localization rate, and number of alive nodes when the velocities of nodes on team 1 were 1 [m/step] and those on team 2 were 4 [m/step]. The localization rate of team 2 was lower than that of team 1. However, team 2 had more wins as can be seen from the scenario B results in Table II. This indicates that the node velocity is an important parameter in the war game.

**D. Impact of obstruction position**

We evaluated the impact of an obstruction by adding one to the field and varying its position. Figure 8 shows snapshots of war games assuming that there is an obstruction at position (250, 100). The height and width of the obstruction were 200 and 200 [m], respectively. The node cannot enter the portion of the obstruction. Figure 8 shows that nodes had trouble moving forward even though the velocities of the nodes on the both teams were the same.

To evaluate the impact of the obstruction’s position, we fixed its x-axis position at 250 and varied its y-axis position. As shown in Fig. 9, the positioning accuracy and localization rate were almost the same when the obstruction’s position was (250, 250). As shown in Fig. 10, when the obstruction’s position was (250, 100), the localization rate of team 2 was lower than that of team 1. This is because the obstruction made the network topology non-convex, making it difficult to estimate the node positions using multi-hop localization [13]. Although the positioning accuracy of team 2 was better than that of team 1, the localization rate was lower. Hence, many nodes were assigned a 100% positioning error. Consequently, the number of alive nodes on team 2 was less than that of team 1. The row for scenario C in Table II shows that the number of wins was closely related to the obstruction’s...
position. This means that the position of an obstruction is a key parameter in a multi-hop localization game.

Since multi-hop localization increases the positioning error in a non-convex network, the characteristics of an obstruction’s position can be considered in team strategies. For example, players can collaborate to move to avoid making a non-convex network in a team’s topology. The characteristics of multi-hop localization open the door to creating various game strategies. The proposed game thus made good use of the ad-hoc networking capability.

VI. CONCLUSION

We developed a wireless multi-hop localization games, i.e., a war game based on the classical field games. It is played using mobile game consoles with ad-hoc networking capability. The fundamental concept underlying a wireless multi-hop localization game is that players on a team establish an ad-hoc network to estimate their positions and then compete for positioning accuracy with other teams using a multi-hop localization technique. Using simulation, we showed that node velocity and obstruction position are important parameters in the war game. The results demonstrated that the proposed game made good use of the ad-hoc networking capability.

In this work, we assumed that the nodes simply moved randomly in order to investigate the primitive operations of wireless multi-hop localization games. However, in the real world, players cooperate to minimize their positioning errors. Such cooperation can be embedded into the node mobility in a simulation to obtain more realistic game results. In future work, we intend to perform detailed evaluations of games played using various strategies and actually played on a field.

REFERENCES