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Wireless Multi-hop Localization Games for Entertainment Computing

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1. Introduction

Ad-hoc networking capabilities have provided the flexibility needed to construct various types of networks without infrastructure base stations. Emerging products for sensor networks, such as Zigbee (1), use ad-hoc networking capabilities to construct networks. These sensor nodes can construct the network such as in outdoor fields and inside buildings without much effort on establishing the base stations, and monitor neighbor information on area where people usually cannot stay for the monitoring. The technique of ad-hoc networking has been discussed within the Internet Engineering Task Force (IETF) by the Mobile Ad-hoc Network (MANET) Working Group (2). MANET is a promising technique to provide the alternative network infrastructure such as in the disaster case that the existing network infrastructures are destroyed because of fires and earthquakes. The wireless terminals with radio capabilities relay data and deliver to a desired destination. Recently, mobile game consoles with ad-hoc networking capabilities have been produced by companies such as Nintendo (3) and Sony Computer Entertainment (SCE) (4). Networking capabilities play an important role in enabling multiple players to join together to play games. 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. To utilize this functionality, some games using ad-hoc networking capabilities have been developed. However, the games released thus far only use ad-hoc networking capabilities for joining the game.

We have developed two wireless multi-hop localization games with ad-hoc networking capabilities, and have presented several initial results in (29). The proposed games, a war game and a tag game, are based on classical field games. Players use mobile game consoles with ad-hoc networking capabilities to move around a field. The games use wireless multi-hop localization to estimate node positions. Players on one 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 (28). We used simulation to evaluate the multi-hop localization games and analyze their characteristics. We found that node velocity and obstruction position controlled the win rate for the games, and maintaining connectivity and local rules led to higher win rates for the games. The results revealed that the proposed games worked well as localization applications using the ad-hoc networking capabilities.

The purpose of this paper is to present new localization applications using ad-hoc networking capabilities. The concept behind multi-hop localization games is presented. Wireless multi-hop localization games are evaluated to find out how well localization-based games with ad-hoc networking capabilities perform in a simulation. These main results obtained from the simulation are summarized as follows.

- The win rate for the games depends on node velocity and obstruction position.
- A higher connectivity constraint leads to a higher win rate for the games.
- Enforcing the local rule of the death penalty enables the win rate to be controlled for the games.

We will next describe the multi-hop localization technique and the current state of mobile games. The localization technique of ROULA is reviewed in Section 3. Section 4 describes our wireless multi-hop localization games, and our evaluation of these is discussed in Section 5. Section 6 concludes the paper with a brief summary and mentions future work.

2. Localization and mobile games

2.1 Multi-hop localization

Multi-hop localization techniques have been discussed for wireless multi-hop networks such as sensor and ad-hoc networks. The motivation behind developing multi-hop localization is wanting to know where the node position is in wireless multi-hop networks by using a small fraction of the anchor nodes. An anchor node is one whose position is known in advance through means such as global positioning system (GPS). Much research has been conducted on how to estimate node positions in wireless multi-hop networks (9–15; 28). Most localization techniques can be categorized into two types. The first is localization by using extra ranging devices, such as ultra sound devices, and the second is localization without using extra ranging devices.

In AHLoS (11), an iterative multilateration by using time-of-arrival (TOA) measurements was proposed to estimate large numbers of node positions with a small number of anchor nodes. The basic idea behind iterative multilateration is that at least three anchor nodes carry out the multilateration to estimate unknown nodes. Once the positions for unknown nodes are estimated by anchor nodes, the nodes are configured as pseudo-anchor nodes. Then, pseudo-anchor nodes join to estimate unknown nodes that remain in the network. Another distance-measurement approach have been extensively discussed in the literature. In (16), robust trilateration using the rigidity of graph theory for flipping avoidance has been proposed. In sweeps (17), algorithms to identify global rigidity were employed to estimate the node positions without flipping for sparse node networks. In (18), an error control algorithm was formulated to mitigate against the error propagation for iterative localization. The distance-measurement approach normally achieves precise positioning accuracy. However it requires extra ranging devices, increasing the cost for all nodes.

The localization scheme without using extra ranging devices has been developed for large-scale sensor networks, and it basically exploits connectivity information of multi-hop networks. In GPS-less (9), anchor nodes first flood beacon packets containing their anchor location information, and unknown nodes estimate their positions by using anchor location information with a Centroid formula. In DV-Hop (10), the positions for unknown nodes in a network are estimated by using average hop-count distances from anchor nodes. First, anchor nodes flood their location information to all other anchor nodes, and calculate the average 1-hop distance. Next, anchor nodes carry out a trilateration to unknown nodes by using

hop-count distances. In AFL (15), the positions of unknown nodes are estimated without using anchor nodes. The basic idea behind AFL is to utilize reference nodes that represents the relative axis in a network. The five reference nodes are automatically selected in the manner described in (15), and they determine relative node positions based on the hop-counts from their reference positions. In REP (19), the hop-count distance in a network with holes is calculated by using boundary detection (20). Boundary detection is a technique that can detect the network boundary with only information on network connectivity. In (21), boundary detection and a Delaunay graph were jointly used to prevent node positions from flipping. The localization scheme without using ranging devices enables nodes to estimate node positions while only using the radio capabilities of a sensor node. Hence, it has great flexibility to enable nodes to be applied to localization in the network.

We previously developed optimized link state routing-based localization (ROULA) (28). ROULA does not require the use of extra ranging devices for any nodes and precisely estimate the node distance by using multipoint relay (MPR) nodes. We thus used ROULA in our proposed games to enable the nodes to estimate their positions. ROULA is described in Section 3.

2.2 Mobile games

Let us now present a brief history of mobile games and discuss different aspects of the proposed multi-hop localization games from these. A number of game consoles have been developed for the entertainment computing market. These game consoles have 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 wired hand-held controller. Famicom supports capabilities for multiplayer games. Two users can play games using two controllers connected by cables to the console.

Mobile game consoles have been developed with ad-hoc networking capabilities, such as Nintendo DS™ in 2004 by Nintendo (3) and Play Station Portable (PSP)™ in 2004 by SCE (4). Many video games on mobile game consoles have been released by game software companies. Hot shots golf™ (6) (“minna no golf” in Japan) is one of popular portable video games for PSP. Hot shots golf supports multiple players by using ad-hoc networking capabilities. However, hot shots golf only uses ad-hoc networking capabilities for joining the game.

Mobile games for ubiquitous computing environments have recently attracted a great deal of attention (23; 26; 27). Many varieties of mobile games have been developed thus far. Geocaching (22) is a GPS-based treasure hunting game for outdoor environments. The basic idea behind geocaching is that players hide and seek out containers called “geocaches”. A player hides a geocache and registers the positions provided by the GPS receiver. Once the geocache is registered and released on the geocaching web site, another player finds the geocache based on the positions. Geocaching is being carried out in the actual field, and everyone can get started by using a GPS receiver and mobile console with Internet capabilities.

Human Pacman (24) is a multiplayer field game using a GPS receiver and wireless networking capabilities. Pacman is a video game for Famicom and was originally developed by Namco (5) in 1980. Human Pacman is real field version of Pacman. Players are assigned to either the Pacman team or the Ghost team. Each team has at least two helpers to assist its own team. Virtual cookies are placed on the map and their positions correspond to a real field. The goals are for the Pacman team to collect all virtual cookies and for the Ghost team to catch all the Pacman players. Can You See Me Now? (CYSMN) (25) is a chase game based on location

Game names	Scoring metrics	Player's behavior for game win	Networking capabilities	Real field use	No. of participants, N_p	Required equipment
Hot shots golf™ (6)	Golf game score	Individual	Used to connect to other players	No	$1 \leq N_p \leq 8$	Mobile console
Classical war game	Hitting with model gun	Individual	Not used	Yes	$2 \leq N_p$	Model guns and goggles
Classical tag game	Avoiding oni and elapsed time	Individual	Not used	Yes	$2 \leq N_p$	None
Geocaching (22)	Collecting geocaches	Individual	Used to display locations of geocaches	Yes	$1 \leq N_p$	Mobile console and GPS receiver
Human Pac-man (24)	Collecting virtual cookies	Individual or group	Used to record player's trajectory	Yes	$8 \leq N_p$	HMD, mobile console and GPS receiver
CYSMN (25)	Avoiding runners and elapsed time	Individual	Used to display locations of players	Yes	$4 \leq N_p$	Mobile console and GPS receiver
Proposed games	Increasing positioning accuracy and elapsed time	Group	Used for ad-hoc connections and position estimations	Yes	$20 \lesssim N_p$	Mobile console and GPS receiver

Table 1. Comparisons of conventional mobile games with proposed games.

information with GPS. Three runners are visible to players' locations through an virtual online map and they run through actual city streets. Players avoid the runners and compete for the time elapsed since joining the game. If a runner gets within five virtual meters of a player, the player is seen and is excluded from the game.

Table 1 summarizes the features of current mobile games and the proposed multi-hop localization games. Our proposed game has novel distinct aspects from the other works. First, our proposed games use ad-hoc networking capabilities. Conventional mobile games use networking capabilities such as wireless local area network (WLAN) to access the game server that provide the players' location information or a virtual map through the Internet. Our proposed games have novel uses for ad-hoc networking capabilities to conduct multi-hop localization in mobile games. Second, the scoring metric for the game is based on the positioning accuracy of the multi-hop localization technique. In some of the literature, localization is described as being "cooperative" (8). Nodes in the wireless network help to connect with one another to establish their relative positions. The positioning accuracy depends on the number of nodes in the network. Hence, nodes are required to cooperate to achieve higher positioning accuracy. Players must cooperative with their own team in the games.

Finally, let us discuss the number of participants in the proposed games. The proposed games require large numbers of participants compared with other games. This is because multi-hop localization without ranging devices requires a large number of nodes to estimate the positions of the nodes (28). ROULA is guaranteed to estimate all node positions when connectivity is about 20 (28). Connectivity indicates how many nodes are connected to other nodes in 1-hop on average. The least number of participants can be reduced further by using localization with ranging devices although improving the performance of the localization algorithm is beyond the scope of this paper.

3. Optimized Link State Routing-based Localization

3.1 Overview of ROULA

In our two wireless multi-hop localization games, the players used ROULA (28) to enable them to estimate their positions. Let us briefly describe the ROULA technique. A more detailed description of ROULA and its performance are described in (28).

Figure 1 has a conceptual representation of ROULA in a non-convex network topology. The basic idea behind ROULA is that each node matches regular triangles that form exactly convex curves, and makes 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. In addition, ROULA is compatible with the optimized link state routing (OLSR) network protocol (30) and uses the inherent distance characteristic of MPR nodes.

A non-convex network topology can occur when nodes cannot be deployed in some areas because of obstructions, e.g., buildings or natural features such as trees or mountains. A non-convex network topology appears to be a non-convex curve if the network is seen from a global point of view. However, if the network is viewed locally, each small set of the network appears to be a convex curve. In other words, a non-convex network topology is composed of partially convex curves. To find these 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. Using the OLSR protocol has two advantages. First, the MPR selection used in OLSR has the inherent characteristic of reducing distance errors in localization without using ranging devices. Second,

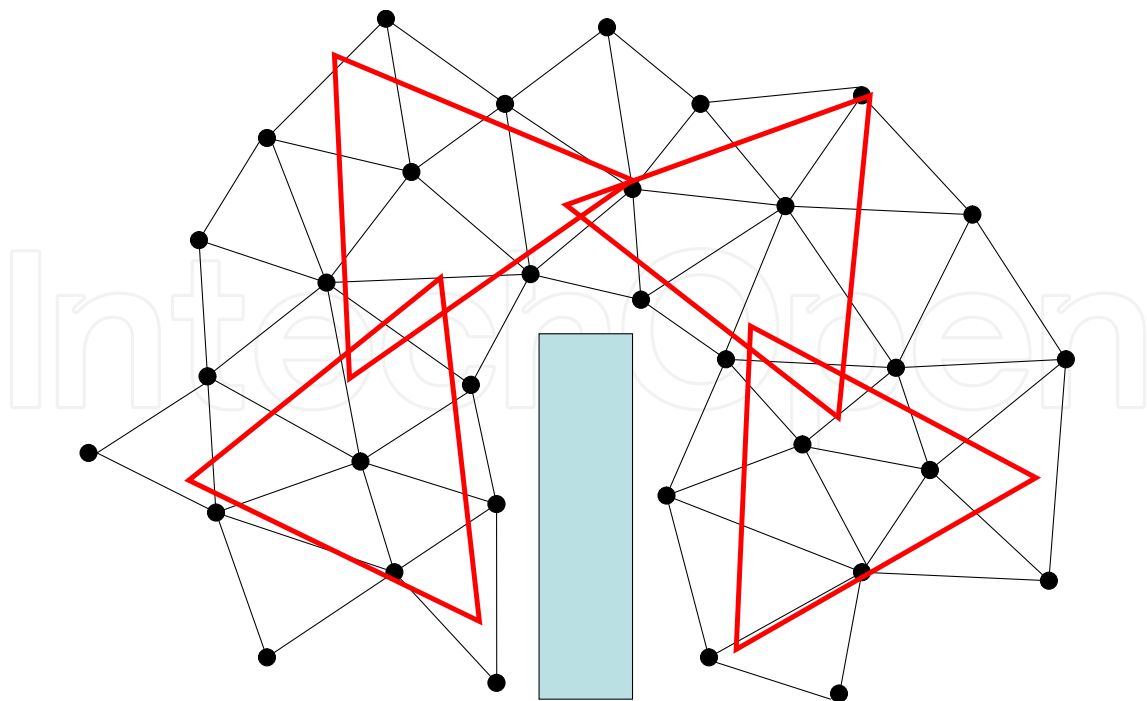


Fig. 1. Conceptual representation of ROULA in non-convex network topology.

nodes in OLSR always hold and update the latest 2-hop node information and MPR nodes in a proactive action that periodically floods hello packets. Node in ROULA localize MPR nodes as their 1-hop nodes without having to make any modifications to the MPR selection. Flooding hello packets and the computational task of MPR selection can be integrated by using the underlying network layer processes.

3.2 Algorithm

The four operations for ROULA are summarized below (28).

1. **Estimating MPR node distances:** Nodes flood hello packets containing their own 1-hop nodes list to their 1-hop nodes. Once a node has a 2-hop nodes list, it selects MPR nodes and estimates the distances between them.
2. **Estimating farthest 2-hop node distances:** Each node selects the farthest 2-hop node for each MPR node and estimates the distances between them.
3. **Estimating relative node positions on regular triangles:** Nodes flood TRI_NOTICE packets to their farthest 2-hop nodes with their farthest 2-hop nodes list. Then, nodes that received TRI_NOTICE packets match regular triangles by using the received farthest 2-hop nodes lists. Nodes then obtain sets of local coordinates by merging their overlapping regular triangles.
4. **Estimating one set of relative coordinates of network:** Sets of relative coordinates are collected and merged into one set of relative coordinates for the network. After that, nodes that have not estimated their positions estimate these by using the Centroid formula (28). If at least three anchor nodes are in the network, the relative coordinates can be converted into absolute coordinates that have the correct network orientation.

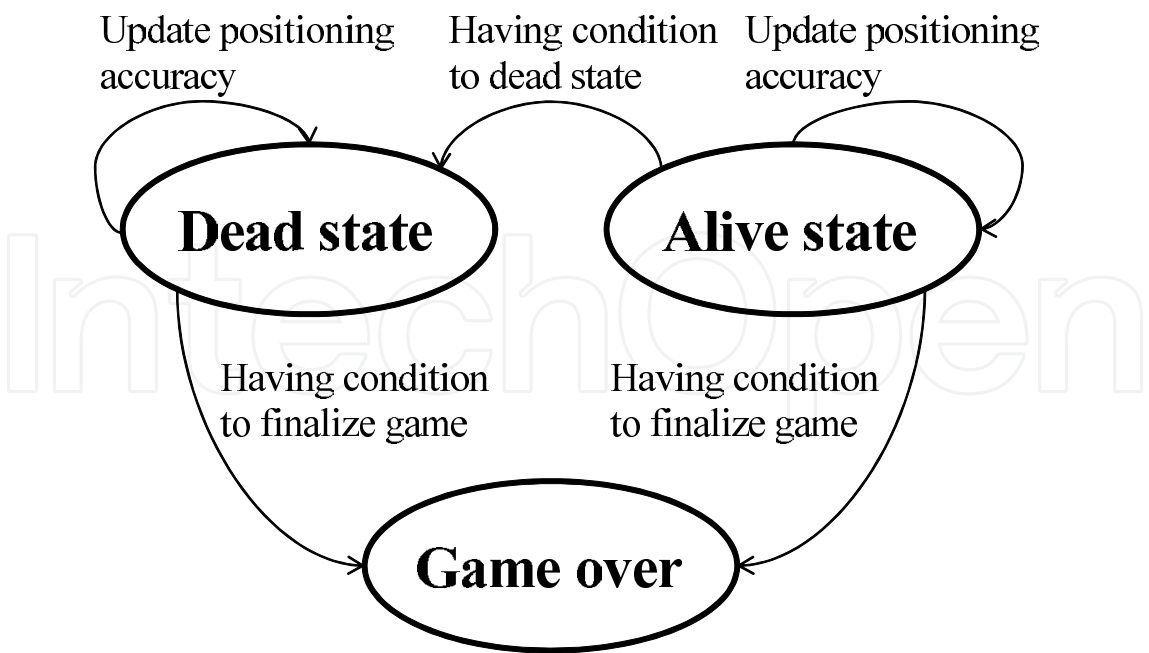


Fig. 2. Principle state transition diagram for multi-hop localization game.

We assume that nodes are deployed in a two-dimensional plane, and a sink node for the network merges all sets of local coordinates in the network. Routing protocol operations are assumed to be done without requiring additional time.

4. Wireless multi-hop localization games

4.1 Overview

The fundamental concept underlying wireless multi-hop localization games 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 capabilities and play the game on a field.

Figure 2 presents a principle state transition diagram for a multi-hop localization game. Each node is either in a “dead” or an “alive” state. 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 state is based on positioning accuracy. The more accurate the positioning obtained by a node, the lower the probability of it transitioning to a dead state. When an alive node satisfies the condition to transition to a dead state, it makes the transition. The condition for finalizing the game is different for each game’s goal.

Two objectives in using ad-hoc networking capabilities are to connect nodes within a limited communications range and to estimate node positions. Once a node is connected 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.

Here, we have simplified the mobility characteristics of human motions to win a game as random motions.

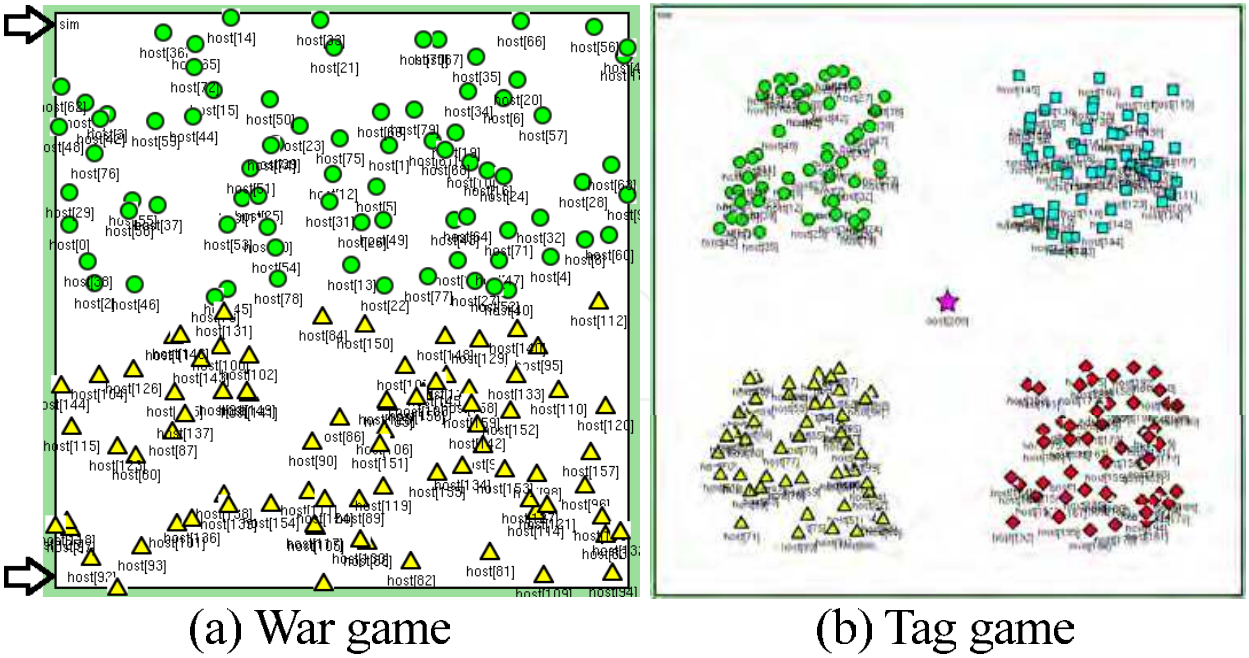


Fig. 3. Initial node placements of (a) war and (b) tag games. Teams 1, 2, 3, and 4 correspond to circles, triangles, squares, and diamonds. Oni is represented by star. Arrows indicate locations of enemy lines.

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 state.
- 7: else if $e_i > e_j$ then
- 8: transition to dead state.

4.2 War game

Let N_{tm} denote the number of teams and N_g 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_g alive nodes on a team to reach the enemy line. $N_{tm}|N_{tm} > 1, N_g|N_g > 0$, and $N_n|N_n \geq N_g$ can be varied. N_{tm} was consistently set to 2 and N_g was set to 1 for the war game discussed here.

Let us consider the case of $N_n = 80$. Figure 3(a) shows the node placement at the beginning of the war game. 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 proceed toward the enemy line. The velocity of each node was determined by using a random variable with an

Algorithm 2 When node i senses hello packet of oni

-
- 1: **if** $\mathcal{U}(0, 100) \leq e_i * \kappa$ **then**
 - 2: Node i transitions to dead state.
-

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 obtained by multi-hop localization as the metric to determine whether a node transitions to a dead state. In the proposed game, all nodes are assumed to be anchor nodes to enable relative coordinates to be converted into absolute coordinates and obtain the positioning error. The positioning error, e_i , is normalized by the communication range, R :

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

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 GPS. When a node cannot estimate its own position, it is assigned a positioning error of 100%. A node transitions to a dead state depending on its positioning error. State transitions algorithm for node i is described in Algorithm 1. In the proposed games, nodes periodically flood hello packets. When a node senses a hello packet, the node receives the packet only if it has arrived from a node on the same team. Otherwise, the node drops the packet and decides whether to transition to the dead state on the basis of 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 a dead state with a probability of 50% (line 5 of Algorithm 1). Otherwise, the node transitions to a dead state if it has a greater positioning error. Once the node transitions to the dead state, it stops moving and receiving packets for localization. If all the nodes on a team transition to dead states, the other team is declared the winner.

4.3 Tag game

Let N_{oni} denote the number of demons (“oni” in Japanese). Each team has the same number of players. The goal of the tag game is for players on each team to survive N_{oni} oni attacks. Players belong to one of the N_{tm} teams. The N_{oni} oni move around the field and never transition to dead states. $N_{tm} | N_{tm} > 0, N_{oni} > 0, \text{ and } N_n > 0$ can be varied. Here, we have consistently considered the case where $N_{tm} = 4, N_{oni} = 1, \text{ and } N_n = 50$ for the tag game.

Figure 3(b) shows the node placement at the beginning of the tag game. Four teams are located in four equal areas. Teams 1, 2, 3, and 4 correspond to the circles, triangles, squares, and diamonds. The oni is located at the center of the field, and is represented by the star. The mobility of the oni and nodes was modeled as a random waypoint. The velocity of each node was chosen by using a random variable with an exponential distribution, $\mathcal{E}(v)$. The nodes periodically run multi-hop localization to estimate their positions.

Algorithm 2 gives the algorithm for node i to transition to a dead state. When node i receives a hello packet from the oni, it transitions to a dead state according to a probability based on its

Field	500 × 500 [m]
Communication range	100 [m]
Node mobility	Random waypoint constrained to advance toward enemy line
Node velocity	$\mathcal{E}(v), v = 1, 2, 4$ [m/step]

Table 2. Simulation parameters for war game

own positioning error. The basic operation of this metric is that if the positioning error is 60%, the probability to transition to the dead state is 60%. In line 1 of Algorithm 2, we introduced design parameter κ to mitigate the impact of positioning error. Our evaluation of the impact of κ is discussed in Section 5.3. We defined max_step , which denotes the maximum length of time for the tag game. The conditions to finalize the tag game are cases where only one team survives or max_step time is up. When max_step is out of time, the winner is the team that has the maximum survival time. The survival time is defined as

$$T_{survive} = \sum_{t=0}^{max_step} \text{number of alive nodes.} \tag{2}$$

In our evaluation, we set max_step to 1000.

5. Evaluation

5.1 Simulation setting

The simulation environment we used was a discrete event simulation environment, OM-NeT++ (31) with Mobility Framework (32). Existing network simulators do not have localization functionality. We implemented localization functionality into OMNeT++. Our localization simulation platform enables to test the localization performance with discrete event simulation. The simulation trials were conducted 30 times with random seeds, and the results were averaged.

5.2 War game

5.2.1 Impact of number of nodes

Table 2 lists the simulation parameters for the war game. The communication range was fixed and we have ignored packet loss in this paper. Hello packets were periodically sent by 5 time step.

Figure 4 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 state. As we can see from Fig. 4(a), the nodes proceeded 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. 4(b).

Figure 5 plots the positioning error, ratio of estimated nodes, 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 the number of nodes contributes to positioning accuracy in multi-hop localization (28). As time went by, the number of nodes that could participate in localization decreased. Hence, the variance in positioning accuracy increased. We defined the ratio of estimated nodes as the

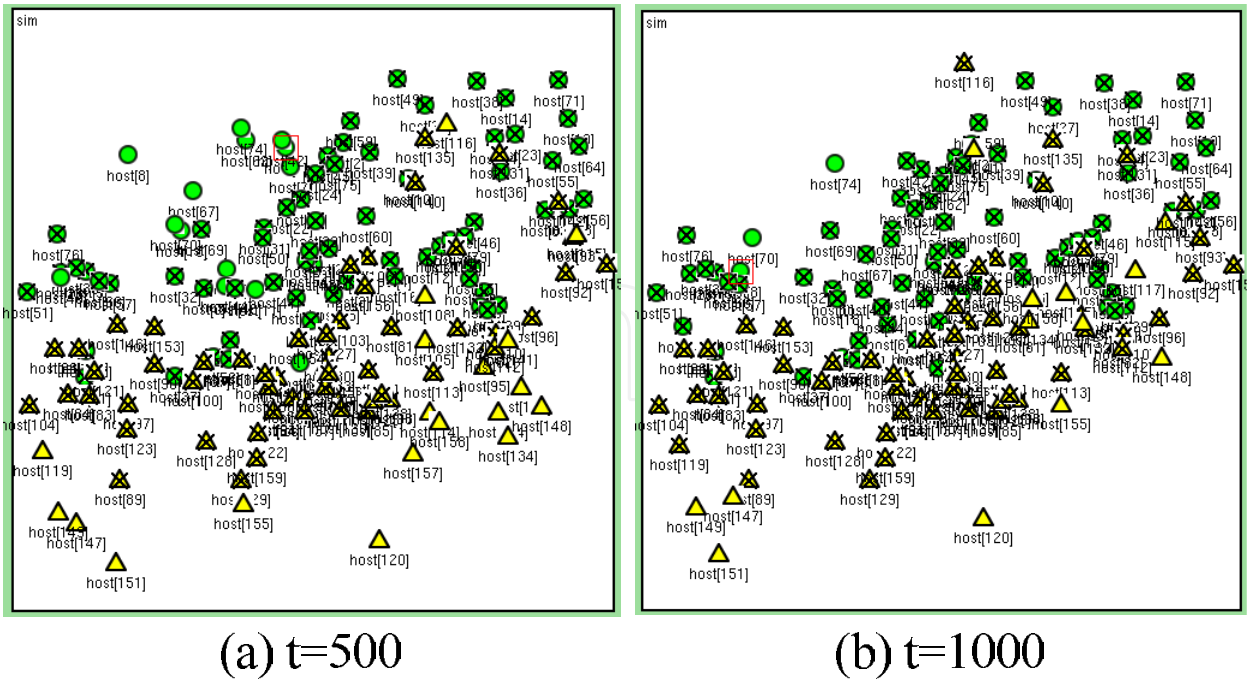


Fig. 4. Snapshots of war games for time steps (a) 500 and (b) 1000 ($N=160, v_{T1,T2}=\{1,1\}$). Nodes for team 1 are represented by circles, and those for team 2 are represented by triangles. Cross on node represents dead state.

percentage of nodes that could estimate their positions 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 ratio of estimated nodes 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 6 plots the results for 160 nodes. Compared with the results for 120 nodes, the ratio of estimated nodes was better, confirming that the number of nodes contributed to the ratio of estimated nodes.

Table 3 lists the number of wins by team for 30 trials with the different parameter settings. The row for scenario A in Table 3 shows that the number of wins for teams 1 and 2 for 120 and 160 nodes, corresponded to 16 and 14, and 15 and 15. 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 ad-hoc networking capabilities.

5.2.2 Impact of velocity

We evaluated the impact of velocity by varying the velocities of nodes on each team. Figure 7 shows snapshots of war games at time steps of 250 and 500 for 160 nodes and the mean node velocities of 1 [m/step] for team 1 and 4 [m/step] for team 2. As seen in Fig. 7(a), the nodes on team 2 were closer to the enemy line than those on team 1. Figure 7(b) shows that many nodes on team 2 died on their enemy's side, and that many nodes on team 1 died on their own side.

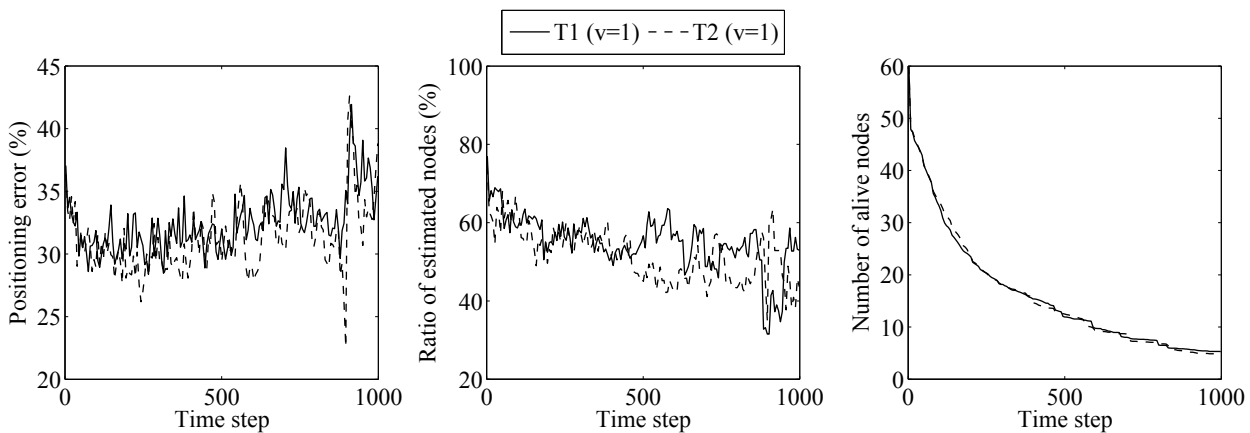


Fig. 5. Positioning error, ratio of estimated nodes, and number of alive nodes ($N=120$, $v_{T1,T2}=\{1,1\}$).

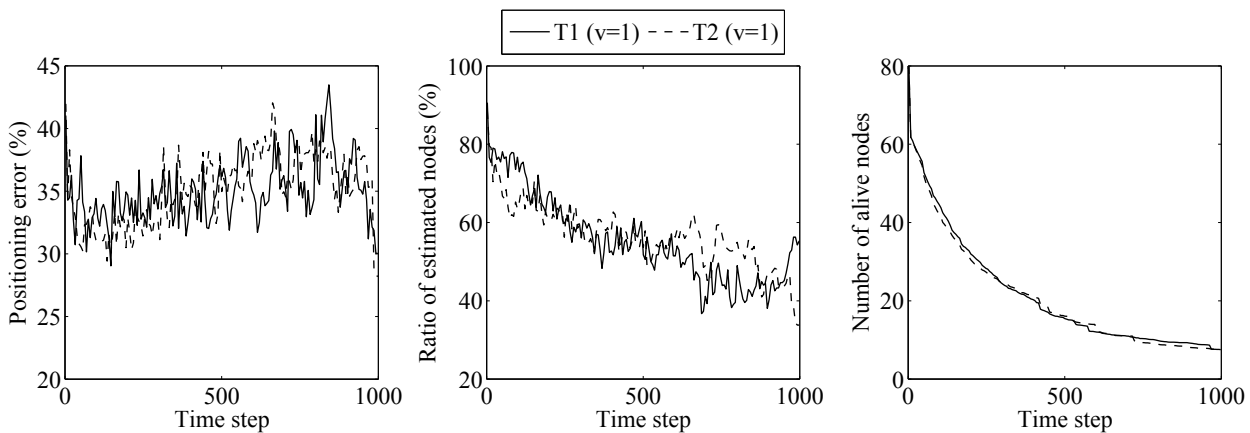


Fig. 6. Positioning error, ratio of estimated nodes, and number of alive nodes ($N=160$, $v_{T1,T2}=\{1,1\}$).

Figure 8 plots the positioning error, ratio of estimated nodes, and number of alive nodes when the velocities of nodes on team 1 were 1 and those on team 2 were 2. The ratio of estimated nodes of team 2 was slightly lower than that on team 1. This is because the nodes on team 2 were more spread out because they moved more quickly, making it more difficult to estimate their node positions using multi-hop localization.

However, the goal of the war game was to reach the enemy line. The row for scenario B in Table 3 indicates the number of wins for teams 1 and 2 for velocities of 1 and 2 [m/step]. Although the ratio of estimated nodes on team 2 was slightly lower than that for team 1, team 2 had more wins. This is because the condition for finalizing the war game was reaching the enemy line; the team with the higher average node velocity had the greater number of wins.

Figure 9 plots the positioning error, ratio of estimated nodes, and the 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 ratio of estimated nodes on team 2 was lower than that on team 1. However, team 2 had

		Team 1	Team 2
Scenario A: N	120	16	14
	160	15	15
Scenario B: $v_{T1,T2}$	{1,2}	12	18
	{1,4}	9	21
Scenario C: y coord. of obst.	250	15	15
	100	29	1

Table 3. Number of team wins in war game. In scenario A, number of nodes N was varied and for $v_{T1,T2} = \{1, 1\}$. In scenario B, the velocity $v_{T1,T2}$ was varied for $N=160$. In scenario C, y coordinate of obstruction was varied for $N=160$ and $v_{T1,T2} = \{1, 1\}$.

more wins as can be seen from the scenario B results in Table 3. This result suggests that the win rate for the war game depends on the node velocity of nodes.

5.2.3 Impact of obstruction position

We evaluated the impact of obstruction position by adding an obstruction to the field and varying its position. Figure 10 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. No node could enter the portion with the obstruction. Figure 10 shows that nodes had trouble moving forward even though the velocities of the nodes on 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 seen in Fig. 11, the positioning accuracy and ratio of estimated nodes were almost the same when the obstruction’s position was (250, 250). As we can see from in Fig. 12, when the obstruction’s position was (250, 100), the ratio of estimated nodes on team 2 was lower than that on 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 (28). Although the positioning accuracy for team 2 was better than that for team 1, the ratio of estimated nodes was lower. Hence, many nodes were assigned a 100% positioning error. Consequently, the number of alive nodes on team 2 was less than that on team 1.

Not surprisingly, the row for scenario C in Table 3 reveals that the number of team wins was closely related to the obstruction’s position. This is because the scoring metric is based on positioning accuracy. The result proved that the win rate for the war game depends on obstruction positions.

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.

5.3 Tag game

5.3.1 Impact of local rule on connectivity constraint

We evaluated the impact of two local rules, i.e, connectivity constraint and death penalty, in the tag game. The connectivity constraint is a rule where the nodes have to avoid situations where the current connectivity becomes less than or equal to a specified connectivity. The connectivity is defined by the number of nodes connected by 1-hop. Thus, nodes have to keep

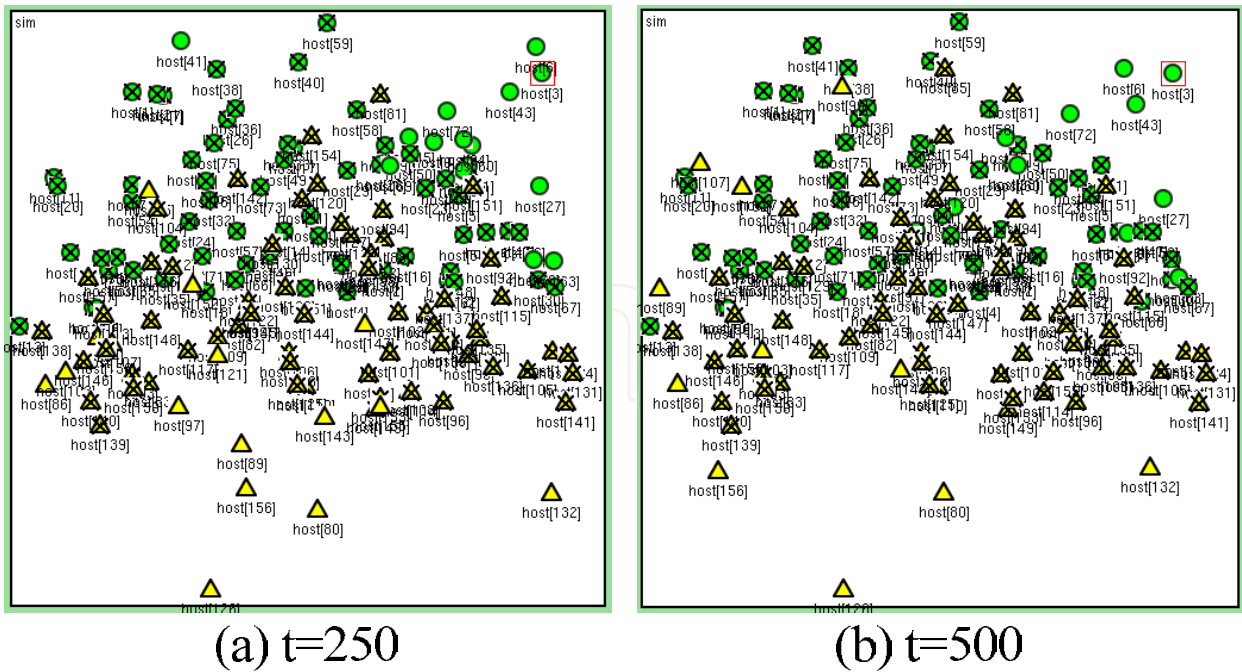


Fig. 7. Snapshots of war games for time steps of (a) 250 and (b) 500 ($N=160$, $v_{T1,T2}=\{1,4\}$). Nodes for team 1 are represented by circles, and those for team 2 are represented by triangles. Cross on node represents dead state.

Field	700 × 700 [m]
Communication range	100 [m]
Number of nodes	200
Node mobility	Random waypoint
Node velocity	$\mathcal{E}(v)$, $v = 1$ [m/step]
Connectivity constraint	$C_{T1,T2,T3,T4}=\{0 \text{ (not applied), } 2, 5, 8\}$

Table 4. Simulation parameters for tag game.

moving to prevent the current connectivity from being violated. The rule of the connectivity constraint can be easy to accomplish in an actual game, because each node can know the current connectivity due to the use of mobile game consoles with ad-hoc networking capabilities. First, we evaluated the impact of local rule of the connectivity constraint. Table 4 presents the simulation parameters for the tag game. Figure 13 shows snapshots of a tag game with the local rule of the connectivity constraint (C). Teams 1, 2, 3, and 4 are located at the top left, bottom left, top right, and bottom right, respectively. The connectivity constraints correspond to 0 (not applied), 2, 5, and 8. As shown in Fig. 13(a), the nodes on team 1 spread over the field while those on team 4 are bunched together. Those on teams 3 and 4 spread gradually, as shown in Fig. 13(b).

Figure 14 plots the results for positioning error, ratio of estimated nodes, and number of alive nodes. The higher the connectivity constraint, the lower the positioning error. This is because the positioning accuracy using multi-hop localization depends on the connectivity (28). The greater the connectivity constraints, the higher the ratio of estimated nodes.

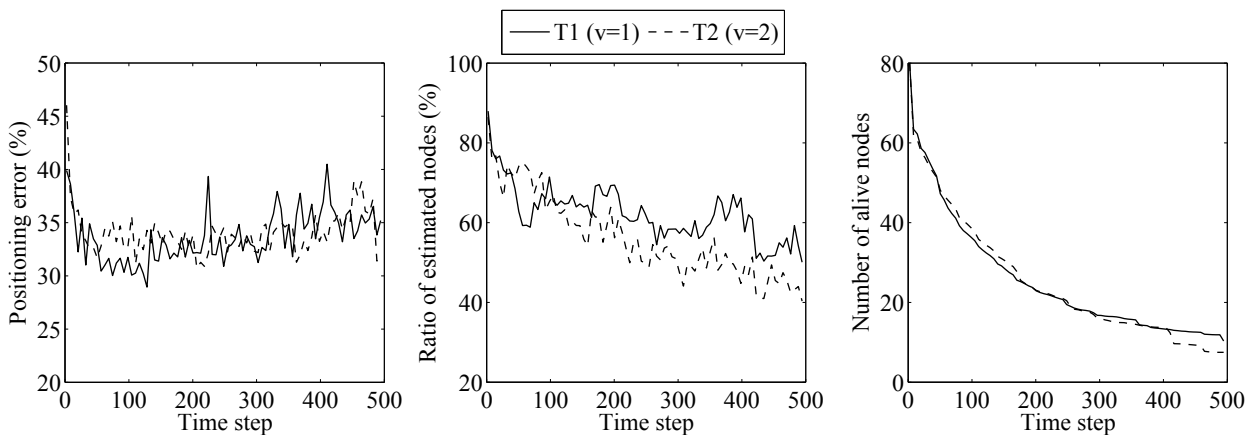


Fig. 8. Positioning error, ratio of estimated nodes, and number of alive nodes ($N=160$, $v_{T1,T2}=\{1,2\}$).

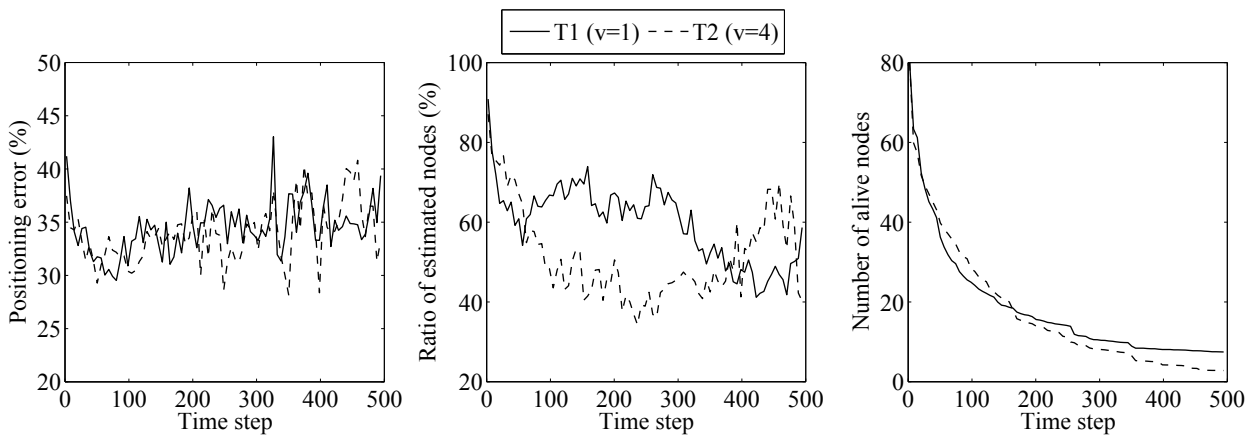


Fig. 9. Positioning error, ratio of estimated nodes, and number of alive nodes ($N=160$, $v_{T1,T2}=\{1,4\}$).

Table 5 summarizes the survival time for the tag game. As seen from the row for scenario D in Table 5, team 1 with a connectivity constraint of 0, had the longest survival time even though it had the lowest localization rate. This is because nodes with a lower connectivity constraint could more readily move around the field. Since the probability of their encountering an oni was lower, nodes with a lower connectivity constraint could survive longer. This result is not suitable for playing the game, because there is no advantage to cooperate for localization, and it does not support the fairness of the game. We thus examined the introduction of a design parameter and a local rule to control the win rate for the game.

5.3.2 Impact of local rule on death penalty

We next evaluated the local rule of a death penalty to impose a penalty for moving alone. The local rule of the death penalty was to impose transition to a dead state when the node could not estimate its own position ω times, consecutively. In addition, we introduced a design parameter κ to mitigate transition to a dead state by using multi-hop localization. The parameter κ encourages the longer survival time in the tag game. κ was introduced in Algorithm 2.

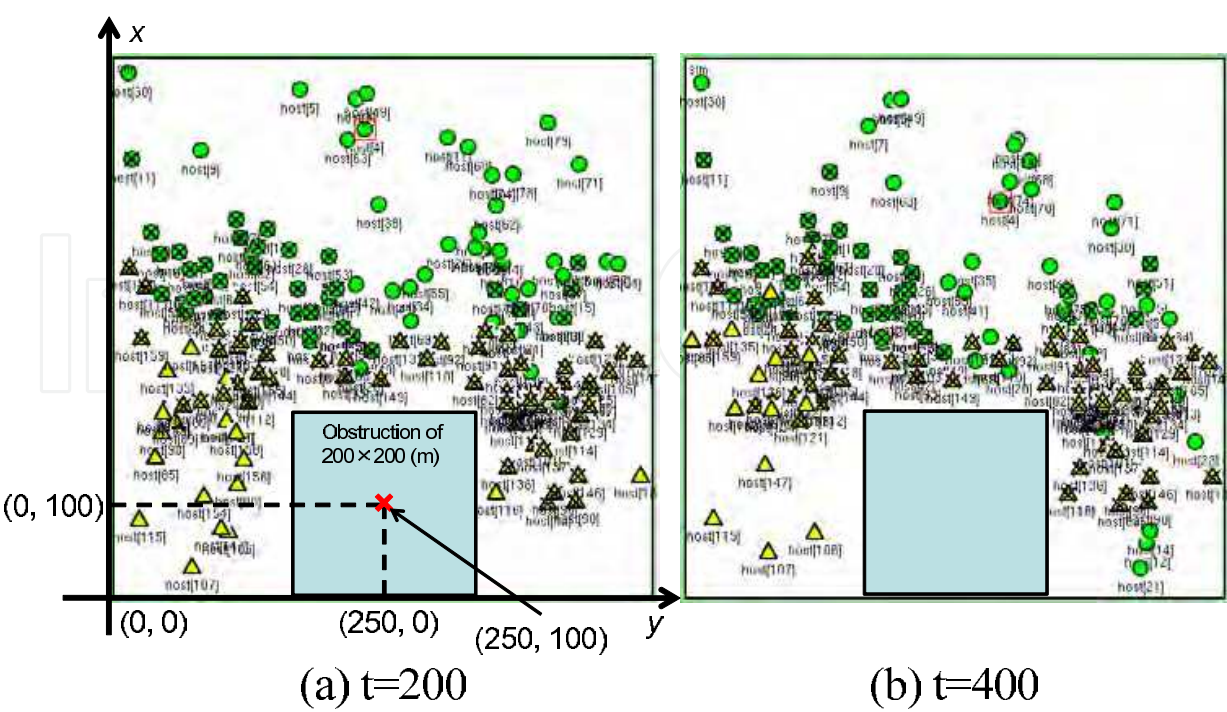


Fig. 10. Snapshots of war game for time steps (a) 200 and (b) 400 with obstruction at (250, 100) ($N=160$, $v_{T1,T2}=\{1,1\}$). Nodes for team 1 are represented by circles, and those for team 2 are represented by triangles. Cross on node represents dead state. Obstructions are drawn as large gray squares.

	Team 1	Team 2	Team 3	Team 4
Scenario D	6429.4	5460.9	5855.8	6001.9
Scenario E	2237.2	2739.4	2937.4	3454.3

Table 5. Survival time in tag game for $C_{T1,T2,T3,T4}=\{0,2,5,8\}$. Scenario D enabled the rule of connectivity constraint. Scenario E enabled the rule of death penalty.

Figure 15 shows snapshots of the tag game with the local rule of the death penalty enabled. Nodes on team 1 with a connectivity constraint of 0 are still widely spread out, however, their death rate is higher due to the local rule of the death penalty. Figure 16 plots the results for positioning error, ratio of estimated nodes, and number of alive nodes with the local rule of the death penalty. The κ was set to 0.5, and ω was set to 2. The number of alive nodes on team 1 decreased over time, because nodes with a lower connectivity constraint had wider dispersion. As we can see from the row for scenario E in Table 5, the higher the connectivity constraint, the longer the survival time. This result demonstrates that the local rule of the death penalty and the design parameters κ , ω effectively maintained the fairness in the tag game.

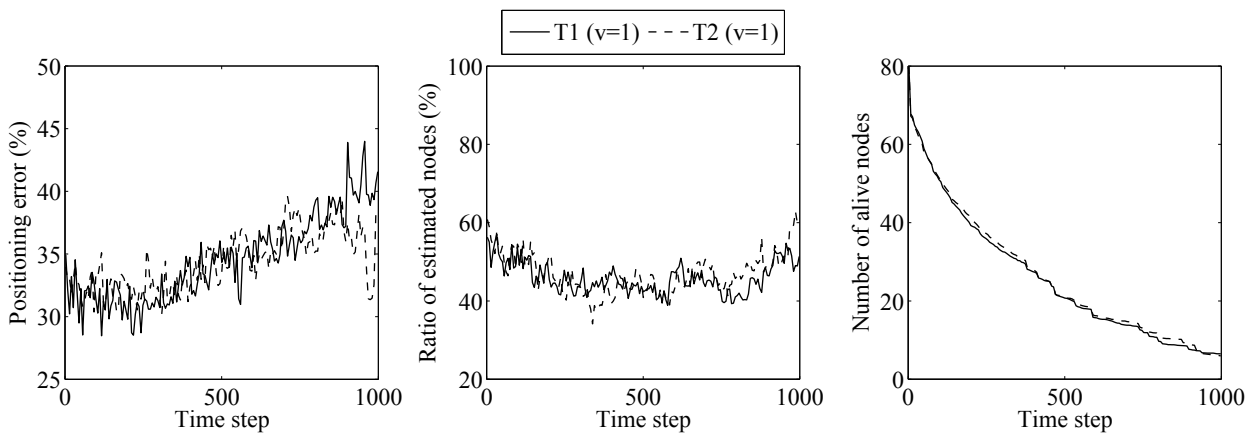


Fig. 11. Positioning error, ratio of estimated nodes, and number of alive nodes with obstruction at (250, 250) ($N=160, v_{T1,T2}=\{1,1\}$).

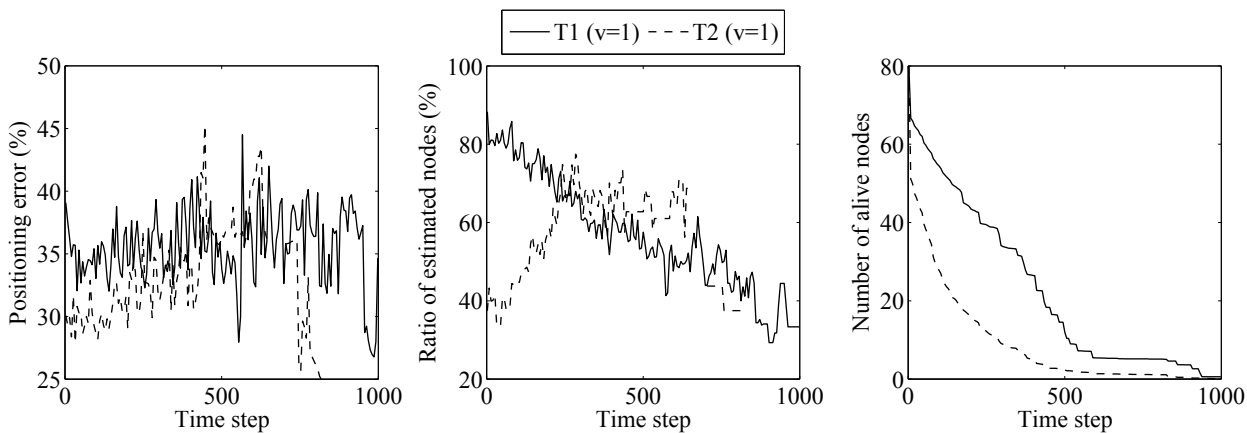


Fig. 12. Positioning error, ratio of estimated nodes, and number of alive nodes with obstruction at (250, 100) ($N=160, v_{T1,T2}=\{1,1\}$).

6. Conclusion

We developed two wireless multi-hop localization games, i.e., a war game and a tag game, based on classical field games. The proposed games are played using mobile game consoles with ad-hoc networking capabilities. 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 obtained using a multi-hop localization technique. Using simulation, we found that node velocity and obstruction positions were parameters to control the win rate for the war game. In the tag game, the higher connectivity constraint led to be surviving longer. The simulations demonstrated that the win rate for the proposed games depends on obstruction positions and connectivity constraint. We also demonstrated that introducing a design parameter and enforcing local rules were needed to control the win rate for the game. The results demonstrated that the proposed games worked well as games with ad-hoc networking capabilities. In this work, we simply assumed that nodes had random motion to investigate the primitive operations of proposed wireless multi-hop localization games. In the real world, players

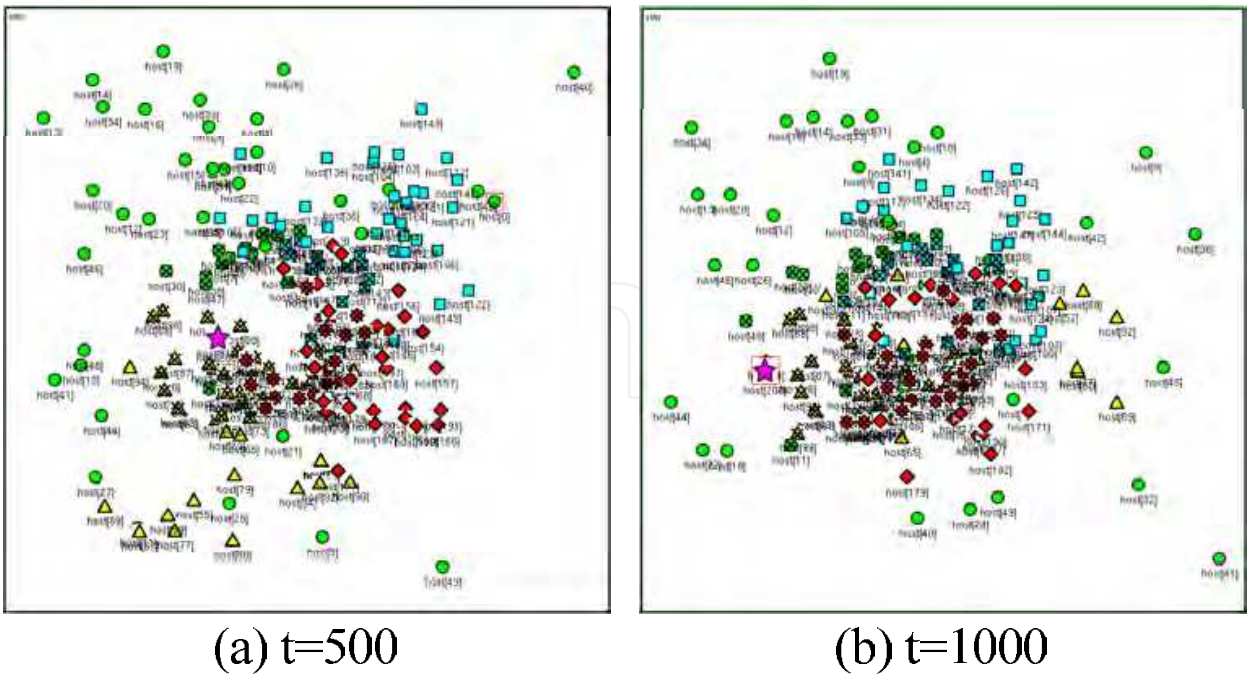


Fig. 13. Snapshots of tag game for time steps (a) 500 and (b) 1000 ($N=200$, $C_{T1,T2,T3,T4}=\{0,2,5,8\}$). Teams 1, 2, 3, and 4 correspond to circles, triangles, squares, and diamonds. Oni is represented by star. Cross on node represents dead state.

would cooperate to minimize their positioning errors, or oni would employ a strategy to track alive nodes. These motions can be embedded into node mobility in simulations to obtain more realistic game results. Since the presented study only covered a range of application proposals on combining ad-hoc networking and multi-hop localization, we suggest that there is a need for further research in terms of appropriateness and effectiveness for the games. Our future work includes detailed evaluations of games with various location-based strate-

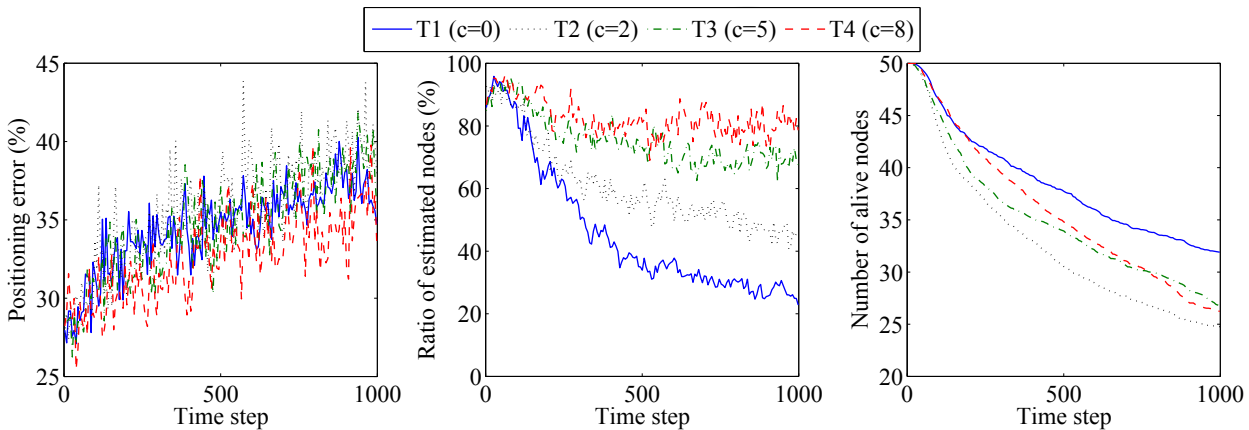


Fig. 14. Positioning error, ratio of estimated nodes, and number of alive nodes ($N=200$)

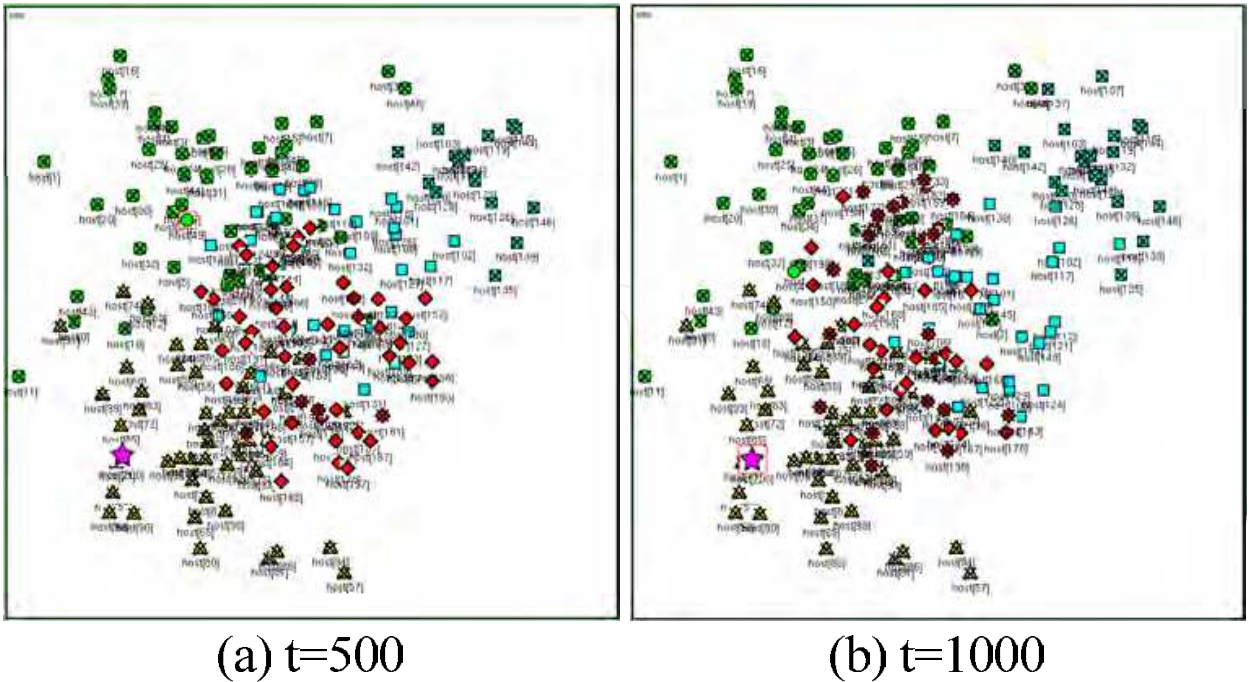


Fig. 15. Snapshots of tag game for time steps (a) 500 and (b) 1000 with local rule of death penalty enabled ($N=200$, $C_{T1,T2,T3,T4}=\{0,2,5,8\}$). Teams 1, 2, 3, and 4 correspond to circles, triangles, squares, and diamonds. The oni is represented by a star. A cross on a node represents a dead state.

gies with positioning errors, actual game testing in the real field, and verifying the degree of user satisfactions when they actually play the proposed games.

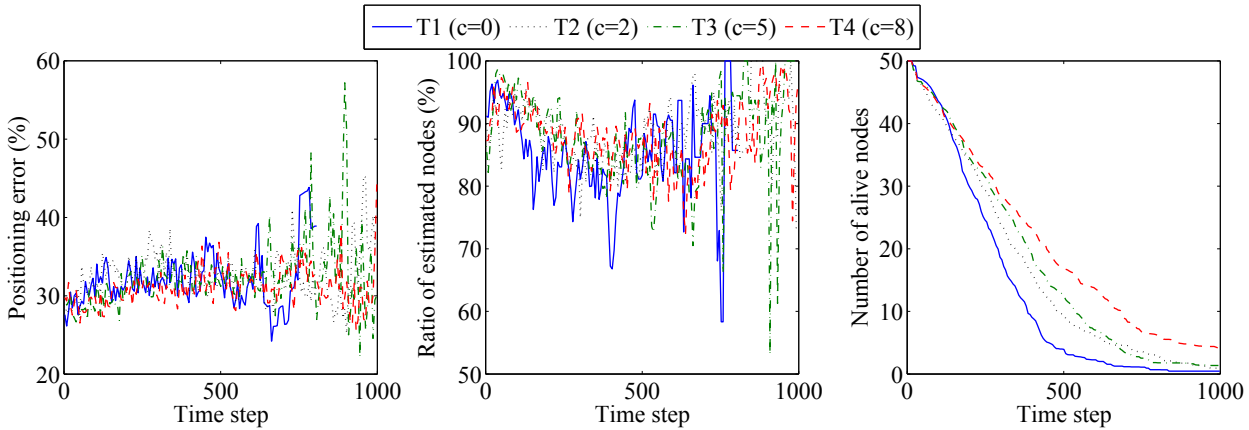


Fig. 16. Positioning error, ratio of estimated nodes, and number of alive nodes with local rule of death penalty ($N=200$, $\kappa = 0.5$ and $\omega = 2$).

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In the last decades the restless evolution of information and communication technologies (ICT) brought to a deep transformation of our habits. The growth of the Internet and the advances in hardware and software implementations modified our way to communicate and to share information. In this book, an overview of the major issues faced today by researchers in the field of radio communications is given through 35 high quality chapters written by specialists working in universities and research centers all over the world. Various aspects will be deeply discussed: channel modeling, beamforming, multiple antennas, cooperative networks, opportunistic scheduling, advanced admission control, handover management, systems performance assessment, routing issues in mobility conditions, localization, web security. Advanced techniques for the radio resource management will be discussed both in single and multiple radio technologies; either in infrastructure, mesh or ad hoc networks.

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