REDUCING NETWORK BANDWIDTH IN COORDINATED TRAINING USING EMBEDDED SIMULATION

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The Inter-Vehicle Embedded Simulation Technology (INVEST) program is dedicated to providing onboard simulations in support of training exercises for tactical vehicles. For a particular vehicle, the onboard simulation is used to provide a virtual model of the vehicle, which then interacts with other virtual vehicles being used in the exercise. The Synchronized Player Model (SPM) part of the INVEST program was conceived to reduce the wireless communications bandwidth between the embedded simulations being used in a coordinated training exercise. This is done by synchronizing the simulations using a high-level behavior command interface, as opposed to the simple dead reckoning techniques currently used by most distributed simulations. In this paper, we describe the prototype development and preliminary results of a set of experiments where we use a software control algorithm for maintaining synchronization. We develop these experiments starting with a baseline system, consisting of the standard dead reckoning algorithms now in use, and compare our results against this known standard. The results indicate promising reductions in bandwidth requirements versus location fidelity errors for an SPM Phase 2 prototype testbed. Future work includes extending SPM synchronization concepts to unit level formation behaviors and the development of a prototype embedded SPM testbed suitable for the INVEST program.

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INTRODUCTION

The Inter-Vehicle Embedded Simulation Technology (INVEST) Science and Technology Objective (STO) is a technology exploration program addressing a flexible go-to-war onboard training and operational capability for the power projection Army of the 21st Century [1]. Current stand-alone simulators will not meet future needs of rapidly deploying forces, so embedded autonomous training technologies are being developed and explored. Benefits of such training technology include allowing for on site task sustainment training, helping to fight the skills decay problem, providing the capability to plan and train for newly developed operations on relatively short notice, and electronically emulating the battlefields of tomorrow to meet a diverse enemy in a wide variety of terrain environments.

A fundamental problem for INVEST training is that current tactical communications do not support the bandwidth required to perform distributed simulation exercises [2]. This is because the INVEST system is designed to use wireless network communication between the vehicles that are being used for the embedded training, which currently results in very low network bandwidth constraints under field conditions. This problem is being addressed from two sides, with communications-related research into increasing the bandwidth available for simulation traffic, and simulation-related research into reducing the simulation demand for bandwidth. A major focus of the simulation-related research deals with the issue of synchronizing multiple live and virtual simulation entities. The current method of synchronizing multiple simulation entities requires frequent broadcast of state information among all players, using Distributed Interactive Simulation (DIS) dead reckoning. In a standard DIS simulation environment, this dead reckoning predicts the entity's location behavior based on location and orientation parameters. When dead reckoning approximation exceeds a synchronization threshold, a vehicle's location/orientation parameters are updated by sending entity state DIS Protocol Data Units (PDUs) across the distributed simulation on very high bandwidth communication channels. Previous work has extended the standard dead reckoning concept using a concurrent model approach. This approach uses a clone reference model of an entity and a Difference Analysis Engine (DAE) component to compare live maneuver performance of the entity with its reference model and develop parameters that are passed to the reference model and its remote entity clones [3].

The Synchronized Player Models (SPM) project is looking at ways to further extend this concurrent model approach by synchronizing player interaction with smaller, less frequent information updates. The objectives of SPM are threefold: 1) Investigate and develop an architecture to support the INVEST STO including the reuse of software components in the development of the synchronized player models, 2) develop a player model simulation that emulates a live system and synchronize it with its clone model simulations, which are distributed throughout the multiple player environment, and 3) decrease bandwidth requirements for achieving this synchronization by developing a communications protocol between local player models and their remote clone models.

PREVIOUS SPM RESULTS

SPM research is being conducted using a multiphase prototype development and experimental effort. This allows previous Phase 1 research results to be fed back into current SPM efforts to tailor and improve SPM prototype functionality. ModSAF 3.0 was selected for Phase 1 experiments due to its availability, with the idea that some modifications were necessary to create experimental SPM prototypes. Phase 1 experiments demonstrated an implementation of a repeatable version of ModSAF 3.0 and prototyped a ModSAF human operator interface to maintain synchronization between a live vehicle and its remote clone [4, 5].

The first part of the Phase 1 effort focused on developing a repeatable SAF simulation, where repeatable means that if two runs of the simulation had identical initial conditions and were run in an identical context, then these runs would produce identical results. This is contrary to current SAF simulations, which use random number generators to maintain the nondeterminism of the simulation runs. ModSAF 3.0 system operations contain areas where randomness or probability occur which affect the outcome of the system (i.e., scheduling) and behaviors. In order to increase synchronization and make ModSAF operations more deterministic, these areas were defined and analyzed to ascertain the best approach for modification. ModSAF component modifications necessary to implement repeatability included decoupling the real-time and simulation clock, altering the simulation queue to be event driven based on the simulation clock, moving behavior and physical model updates to the simulation queue, and implementing a repeatable random number string between separate executions.

The next part of the Phase 1 effort looked at the communication requirements associated with synchronizing distributed simulation vehicles at various ModSAF model levels. Currently, most simulated entities are synchronized using *dead reckoning.* In this technique, position and velocity for the entity are sent out at periodic intervals by a master model of the entity. Other simulations maintaining a model for the entity maintain its position between updates by extrapolating from the current position using the supplied velocity vector. The master model for the entity is responsible for comparing its actual position against the dead reckoned position, and sending out the periodic updates when the distance between the two positions is outside an input tolerance. While simple, this approach requires frequent updates, resulting in high network traffic.

To address this current high network traffic issue, we performed communications analysis on the lower physical and behavioral model levels of ModSAF 3.0 to determine data flow and model instrumentation impact on vehicle synchronization issues. During model analysis, the specific behavior and physical models involved in the experimental scenario were identified and the data flow between the behavior and physical models was ascertained. This analysis was necessary to determine where to best apply vehicle synchronization inputs and what parameters were needed to be manipulated for a live vehicle Difference Analysis Engine (DAE) Control Interface. The result of this data flow analysis was the selection of the behavior model level as the best point of synchronization control in ModSAF.

The final part of our Phase 1 effort focused on looking at the feasibility of using a DAE to control the operation of the live vehicle clones. To do this, we substituted a human controller for the DAE. We provided the human controller with a set of simulated live vehicle inputs and a behavioral control interface for controlling the live vehicle reference model. An important finding from these experiments was that simply allowing frequent reference model corrections did not necessarily result in better synchronization. We discovered that there needs to be a match between the accuracy of the reference model control and the frequency of update. Fewer but more accurate corrections provide improved synchronization when compared to more frequent but less accurate corrections.

AUTOMATED SPM PROTOTYPE DEVELOPMENT

In SPM Phase 2, an automated SPM prototype testbed is being developed which uses vehicle level software control algorithms to maintain distributed synchronization between a live vehicle and its remote clone models. Figure 1 shows a simplified representation of a distributed SPM model simulation. This SPM simulation model emulates a live vehicle (Vehicle A on the left) and synchronizes it (through high level behavioral control) with its Vehicle A remote clone model simulation, which is distributed and running on another live vehicle (Vehicle B). This synchronization enables real world vehicles to maintain a common virtual world view of other live and virtual battlefield entities participating in a training event.

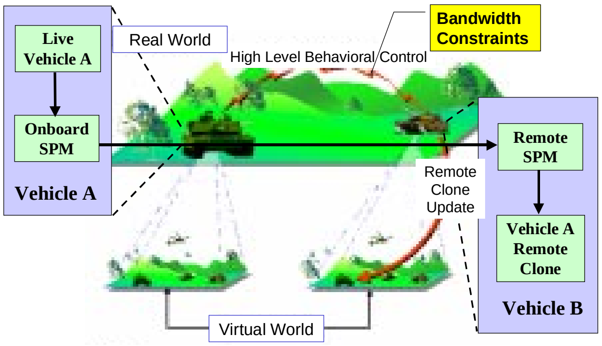


Figure 1. Simplified SPM System

The focus of this automated SPM prototype, which is being developed using ModSAF 4.0 libraries, is the Onboard SPM component shown in the left of Figure 1 and below in Figure 2. Canned Live Vehicle data is input and compared to the onboard SPM clone model data of the live vehicle. This is done using an Automated Difference Tool which compares live and SPM clone maneuver information (e.g., location and speed) to threshold values. When position-related differences are detected above a set threshold, one or more Automated Route Control atomic techniques is selected and control updates are sent to the Onboard PO

Database to update the Onboard SPM clone model. Even though it is not currently implemented in the testbed, the same control updates need to be sent via wireless LAN to distributed remote SPMs located on other live vehicles, such as Vehicle B on the right side of Figure 1. These transmissions update remote clone models of Vehicle A to maintain SPM synchronization between vehicles.

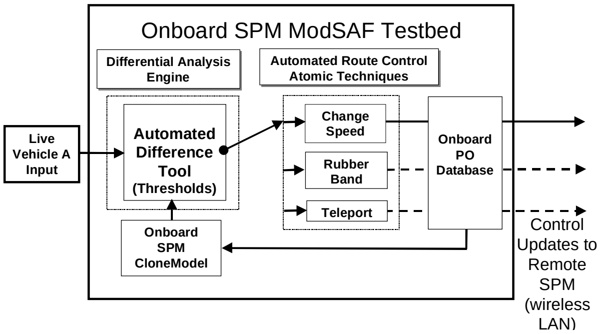


Figure 2. Onboard SPM ModSAF Testbed Components

The three atomic techniques being used for the Onboard SPM are Change Speed, Rubber Band, and Teleport (see Figure 2). The *Rubber Band* atomic technique replaces the SPM clone route with a new route along the live vehicle's most recent velocity vector when a distance threshold parameter is exceeded. The technique is activated based on a threshold distance between the live vehicle and SPM locations. The new route is created with a near point and far point in front of the live vehicle along this vector, which is calculated by using live vehicle velocity as an input parameter. This enables the SPM clone to initially close distance with the live vehicle while maintaining a consistent orientation towards the live vehicle's projected location. Once the SPM clone reaches the near point, it travels on the same velocity vector as the live vehicle.

The *Change Speed* atomic technique increases or decreases the SPM clone model speed if a speed threshold parameter is exceeded based on the difference between the live vehicle and SPM speeds. The SPM clone speed is changed using a spring dash pot algorithm which uses the distance and velocity vectors between live and SPM clone vehicles as input parameters to speed changes.

$$New\_SPM\_Speed = [Gain\_const * \pm f(Distance, Velocity)] \\ - Damping\_const[SPM\_speed - live\_speed] + Live\_speed$$

The following describes the two extreme cases of distance and velocity vector situations which can occur between the live and SPM clone. If the SPM clone model is on a direct intercept course to the live vehicle, a speed change will take effect as soon as the distance threshold is met and the speed change will be maximized, causing it to close quickly on the live vehicle. If the SPM clone and live vehicle are running parallel to each other (racing), a speed change will never take effect and speeds will be matched. This algorithm allows the SPM clone speed to be based on distance from the live vehicle, which causes the SPM clone to lock onto the live vehicle speed and position while minimizing overshooting of the live vehicle's location.

The *Teleport* atomic technique immediately changes the SPM clone's location and orientation parameters to that of the live vehicle when a distance threshold parameter is exceeded based on distance between the live vehicle and SPM locations. All atomic techniques are given a time delay to take effect before a new control update is sent.

EXPERIMENTAL METHOD

Overview

Using the above described automated SPM prototype testbed, a set of experiments was designed in Phase 2, which replaces the human decision maker (used in SPM Phase 1 experiments) with software control algorithms for maintaining synchronization of a live vehicle. This approach has the benefit of utilizing a much higher data bandwidth than can be processed by a human, and can provide corrections in a vastly reduced time frame. We developed these experiments starting with a baseline system, consisting of the standard dead reckoning algorithms now in use, and are comparing our results against this known standard. Phase 2 experimentation is currently being conducted. Emerging experimental results consist of bandwidth requirements versus location registration errors.

Scenario Development

In order to explore a range of live vehicle route maneuver situations, four armored ground maneuver scenarios were developed for Phase 2 experiments. The Ft. Hood, Texas terrain database was used for scenario creation and routes were created in the vicinity of Blackwell range, since future INVEST demonstrations are planned to be conducted in this area. Based on a doctrinal review of armored vehicle driver training [6] and tank platoon maneuver techniques [7], as well as subject matter expert (SME) input, a number of common armored maneuver primitive vehicle behaviors were selected for scenario use. These maneuver primitives were selected to each exhibit a distinctly different low-level pattern of common tactical maneuver which could be used alone or in groups of primitive segments to build composite vehicle cross-country routes. The scenario routes increase in complexity by increasing the number and shape features of maneuver primitives.

Scenario 1 uses a single *sprint* segment (see Figure 3). The *sprint* primitive is simply a straight line route which could be used across open terrain when vehicle speed is essential and the risk of detection is a lower priority. Speed changes are possible, but no direction changes occur in Scenario 1.

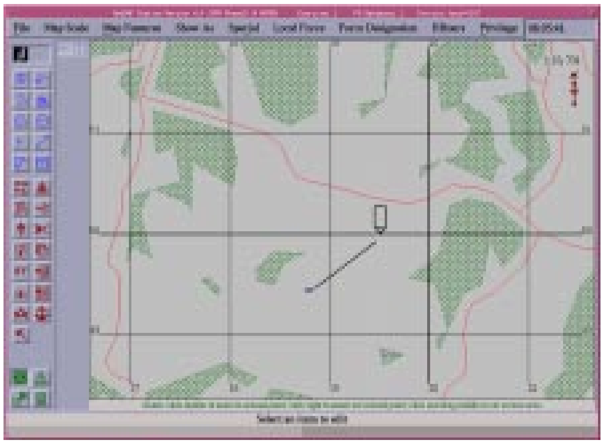


Figure 3. Scenario 1-Sprint

Scenario 2 uses a single *terrain following* segment (see Figure 4). The *terrain following* primitive is composed of multiple (six) abrupt direction changes which is typical of close terrain following with low vehicle speed to minimize risk of detection. Abrupt direction and speed changes occur in Scenario 2.

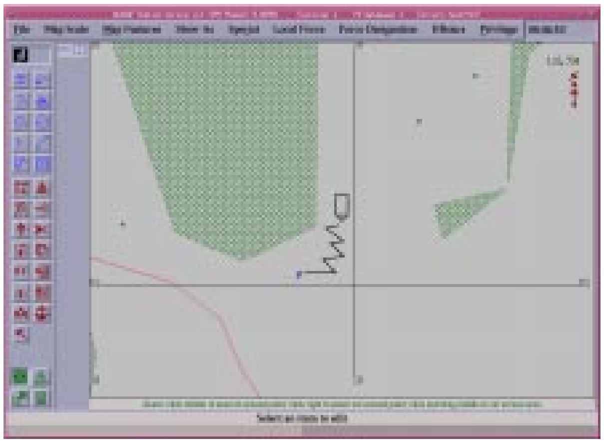


Figure 4. Scenario 2-Terrain Following Direction Changes

Scenario 3 uses a combination of an *obstacle*, *sprint*, and another *obstacle* segment (see Figure 5). The *obstacle* primitive is composed of a route through or closely around a non-trafficable terrain area. All green vegetation areas in these scenarios is treated by ModSAF as non-trafficable obstacles and vehicles will be diverted by ModSAF around these vegetation areas. Direction and speed changes occur in Scenario 3 obstacle segments and only speed changes occur in the sprint segment.

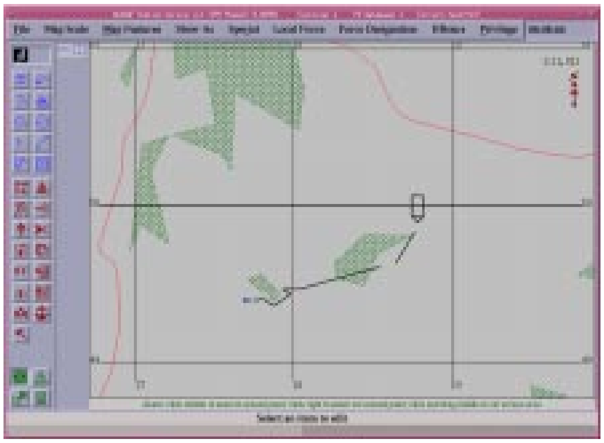


Figure 5. Scenario 3-Obstacle/Sprint/Obstacle

Scenario 4 uses a combination of *sprint*, *terrain following*, and *echelon left* segments (see Figure 5). The *sprint* primitive is the first straight line segment. The terrain following segment consists of the next seven route lines exhibiting severe direction changes. The *echelon left* primitive is composed of a curved route, which results in a gradual overall change in vehicle direction using the last five route lines. Such curved echelon movements are commonly used as part of small unit action drills to maintain formations while doctrinally reacting to mission, enemy, and terrain influences. Speed changes occur during the Scenario 4 sprint segment, abrupt direction and speed changes occur during terrain following and numerous minor direction and speed changes occur during the echelon left segment.

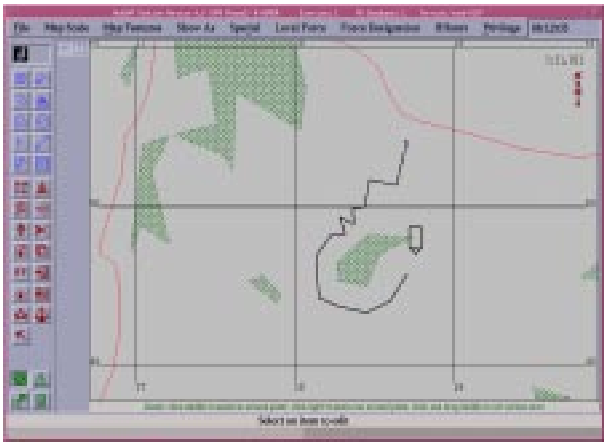
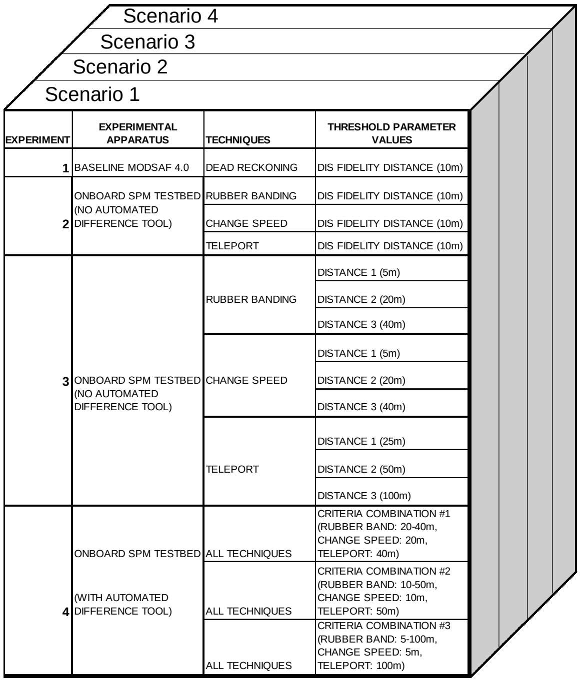


Figure 6. Scenario 4-Sprint/Terrain Following/Echelon Left

Experimental Design

The experimental design used for the SPM Phase 2 study is graphically portrayed in Figure 7. A series of four experiments is being conducted using the same set of four live vehicle route scenarios across all experiments. Using these scenarios, the bandwidth and spatial positioning during control updates is collected over time and analyzed. The experimental series starts with Experiment 1 using a baseline ModSAF 4.0 system as the experimental apparatus[1]. The synchronization techniques for baseline ModSAF 4.0 are standard dead reckoning algorithms and maneuver difference thresholds now in use for DIS entity state PDU updates. The DIS difference threshold most relevant to SPM research is a distance threshold of 10m. These existing DIS maneuver-related thresholds can be viewed as a "DIS fidelity" for a simulated entity's distributed maneuver synchronization. For each scenario, a ModSAF entity is run along the route and the entity state PDU count is logged per second until path completion. The byte count is then calculated, based on entity state PDU size.



EXPERIMENT	EXPERIMENTAL APPARATUS	TECHNIQUES	THRESHOLD PARAMETER VALUES
1	BASELINE MODSAF 4.0	DEAD RECKONING	DIS FIDELITY DISTANCE (10m)
2	ONBOARD SPM TESTBED (NO AUTOMATED DIFFERENCE TOOL)	RUBBER BANDING	DIS FIDELITY DISTANCE (10m)
		CHANGE SPEED	DIS FIDELITY DISTANCE (10m)
		TELEPORT	DIS FIDELITY DISTANCE (10m)
3	ONBOARD SPM TESTBED (NO AUTOMATED DIFFERENCE TOOL)	RUBBER BANDING	DISTANCE 1 (5m)
			DISTANCE 2 (20m)
			DISTANCE 3 (40m)
		CHANGE SPEED	DISTANCE 1 (5m)
			DISTANCE 2 (20m)
			DISTANCE 3 (40m)
		TELEPORT	DISTANCE 1 (25m)
			DISTANCE 2 (50m)
			DISTANCE 3 (100m)
4	ONBOARD SPM TESTBED (WITH AUTOMATED DIFFERENCE TOOL)	ALL TECHNIQUES	CRITERIA COMBINATION #1 (RUBBER BAND: 20-40m, CHANGE SPEED: 20m, TELEPORT: 40m)
		ALL TECHNIQUES	CRITERIA COMBINATION #2 (RUBBER BAND: 10-50m, CHANGE SPEED: 10m, TELEPORT: 50m)
		ALL TECHNIQUES	CRITERIA COMBINATION #3 (RUBBER BAND: 5-100m, CHANGE SPEED: 5m, TELEPORT: 100m)

Figure 7. SPM Phase 2 Experimental Design

In Experiments 2 and 3, the Onboard SPM ModSAF 4.0 testbed, without an automated difference tool to select from atomic technique options, is used as the experimental apparatus to synchronize a live and Onboard SPM clone model. Experimental results are then compared against the baseline ModSAF bandwidth results collected in Experiment 1. In Experiment 2, the atomic techniques of Rubber Band, Change Speed and Teleport are used separately on all scenarios. Experiment 2 uses the same "DIS fidelity" maneuver difference threshold values as the baseline ModSAF 4.0 used in Experiment 1. Experiment 3 also uses each atomic technique separately on all scenarios. However, in Experiment 3, the threshold parameters for the respective techniques are varied from "DIS fidelity" to values which are more realistic for embedded SAF training fidelity. A range of three values is used for each technique's threshold distance parameter. Rubber Band and Change Speed thresholds are varied at 5, 20, and 40 meters to bracket the 10 meter DIS fidelity distance threshold. Teleport is varied at a greater threshold distance range of 25, 50 and 100 meters since this technique produces unnatural instantaneous location changes and is planned to be used when other techniques have not synchronized the live vehicle and SPM clone.

In Experiment 4, the Onboard SPM ModSAF 4.0 testbed, including an automated difference tool to select from atomic technique options, is used as the

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[1] Experimental apparatus refers to the testbed software system being used to conduct an experiment's runs.

experimental apparatus. This apparatus allows all three atomic techniques to be used in combination on scenario experimental runs. A combined threshold criterion is implemented in the automated difference tool using distance and speed parameters. Three candidate criteria combinations are shown in Figure 7, based on promising results from pilot atomic technique runs of Experiment 3. The following describes the candidate criteria for the Experiment 4 automated difference tool using combination #2 as an example: The threshold value being used to activate the Rubber Band technique is a distance between the live and SPM clone of greater than 10 meters and less than 50 meters. The threshold value being used to activate the Change Speed technique is distance between the live and SPM clone of greater than 10 meters. The threshold being used to activate the Teleport technique is a distance between the live and SPM clone of greater than 50 meters. Pilot runs have indicated that matching the distance thresholds of the Rubber Banding and Change Speed techniques results in better synchronization performance.

PRELIMINARY RESULTS AND ANALYSIS

The above series of experiments are currently being conducted and pilot runs on selected experiments are yielding encouraging results for vehicle level synchronization. Scenarios 1 and 4 were used for these pilot runs to test a range of scenario routes from Scenario 1's simple sprint to Scenario 4's more complex sprint/terrain following/echelon left. Table 1 shows preliminary bandwidth and fidelity results on Scenarios 1 and 4 using Experiment 1's baseline ModSAF and Experiment 4's SPM Automated Difference Tool ModSAF with threshold criteria combination #2 (Rubber Band: 10-50m, Change Speed: 10m, Teleport: 50m). Scenario 1's straight line Sprint route shows an 89.9% reduction in bandwidth, from 133.61 to 13.50 bytes/sec. The SPM ModSAF fidelity was 6.43 meters, which is less than 10 meter DIS fidelity. Scenario 4's more realistic sprint/terrain following/echelon left route shows a 52.7% reduction in bandwidth, from 195.68 to 92.51 bytes/sec. The SPM ModSAF fidelity distance was 9.78 meters, compared to a 10 meter DIS fidelity.

Table 1. Preliminary Experimental Results

Scenario	Exp. 1 (Baseline ModSAF 4.0) Avg. Bandwidth (bytes/sec)	Exp. 4 (SPM ModSAF) Criteria # 2 Avg. Bandwidth (bytes/sec)	% Reduction in Bandwidth	Exp. 4 (SPM ModSAF) Criteria # 2 Avg. Distance Fidelity (m)
1	133.61	13.50	89.9%	6.43
4	195.68	92.51	52.7%	9.78

Scenario 1 bandwidth and fidelity data are graphically shown across scenario time in Figures 8 and 9 below. In Figure 8, Experiment 1's baseline ModSAF bandwidth is shown with square data points and Experiment 4's SPM Automated Difference Tool ModSAF (threshold criteria combination #2) is shown with triangular data points. In both cases, there is initially a surge in bandwidth as control updates synchronize maneuver models. After 10 seconds of scenario execution, bandwidth has settled into a relatively steady state of mostly 150 bytes/sec increments for baseline ModSAF as compared to mostly 0 bytes/sec increments for SPM Automated ModSAF along this straight sprint route. Figure 9 portrays the SPM Automated ModSAF live versus SPM clone fidelity across Scenario 1 execution time. After an initial peak of 11.5 meters at 3 seconds, the distance difference does not exceed 10 meters for the remainder of the route. The correlation of rubber banding control updates (represented by bandwidth peaks in the SPM ModSAF data of Figure 8) with fidelity threshold peaks approaching 10 meters in Figure 9 can be seen at 36, 64, 69, and 85 seconds. The average live versus SPM clone distance fidelity for Scenario 1 is 6.43 meters (see Table 1).

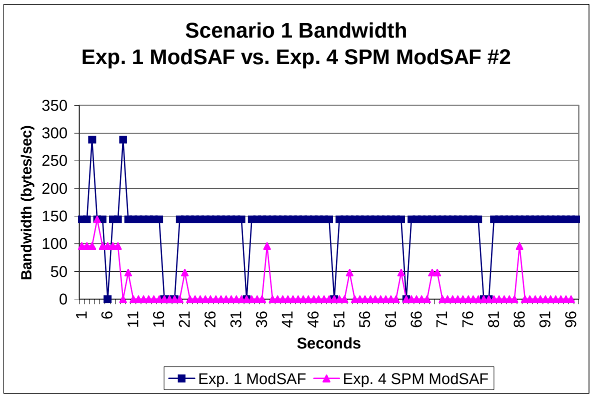

Figure 8. Scenario 1-Exp. 1 versus Exp. 4 Preliminary Bandwidth Comparisons

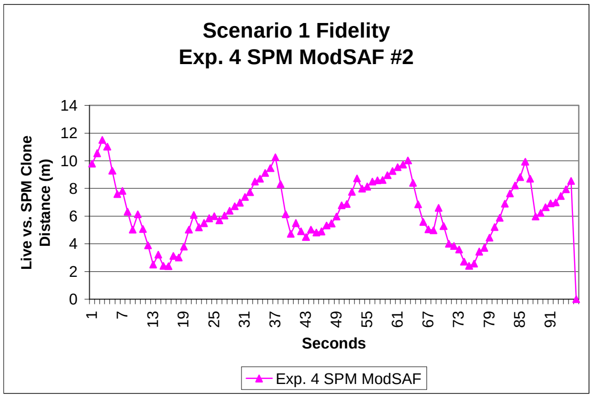

Figure 9. Scenario 1-Exp. 1 versus Exp. 4 Preliminary Fidelity Results

Scenario 4 bandwidth and fidelity data are graphically shown across scenario time in Figures 10 and 11 below using the same experimental apparatus and threshold parameters as in Scenario 1 above. As previously shown in Figure 6, Scenario 4 is a complex route consisting of sprint, terrain following, and echelon left primitive segments. The initial sprint segment maneuver occurs from 0 until approximately 36 seconds. The terrain following segment occurs from approximately 36 to 162 seconds and the echelon left segment lasts from about 162 seconds until scenario completion. Concerning the baseline ModSAF bandwidth, there are periodic surges to 300 bytes/sec during all segments. Occasional surges in the 440 and 580 bytes/sec range occur during terrain following and frequent surges in the 440 bytes/sec range occur during echelon left movement. In contrast, the SPM Automated ModSAF bandwidth has an initial surge to 200 bytes/sec in the sprint segment and frequent sustained surges up to 200 bytes/sec during terrain following and echelon left maneuvers. Figure 11 portrays the SPM Automated ModSAF live versus SPM clone fidelity across Scenario 4 execution time. A decreasing distance during the sprint segment is replaced by a constant cyclical trend during terrain following from 3 to up to 18 meters. During echelon left, a decreasing cyclical trend is observed with the largest distance surges at 22 and 20 meters. These large distance surges occur at 200 and 255 seconds and correspond to large direction changes in the echelon left segment. There is an overall correlation between control update surges (represented by bandwidth peaks in the SPM ModSAF data of Figure 10) and fidelity threshold peaks shown in Figure 11. The average live versus SPM clone distance fidelity for Scenario 4 is 9.78 meters (see Table 1).

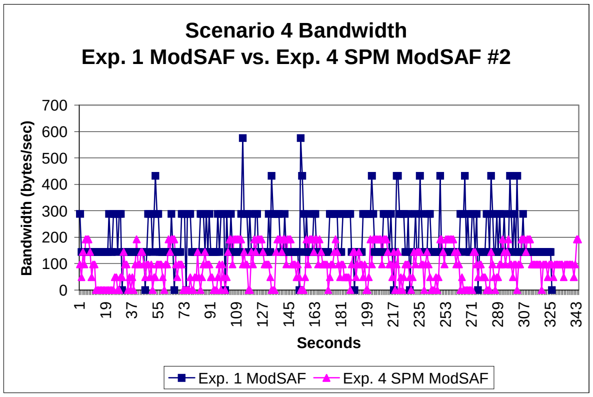

Figure 10. Scenario 4-Exp. 1 versus Exp. 4 Preliminary Fidelity Results

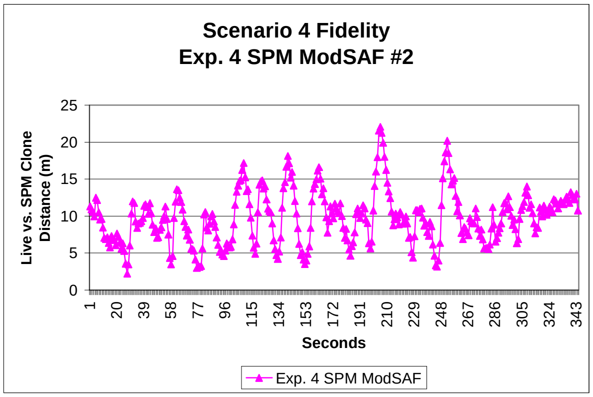

Figure 11. Scenario 4-Exp. 1 versus Exp. 4 Preliminary Fidelity Results

CONCLUSIONS

The above SPM Phase 2 preliminary results indicate that the automated vehicle level software control algorithms used in the SPM Phase 2 testbed can reduce synchronization bandwidth by approximately 50% for a complex maneuver route and 90% for a straight line route. The spatial fidelity associated with these synchronization updates averages from approximately 10 meters for a complex route to 7 meters for a simple route. The combined use of rubber banding, change speed, and teleport techniques, using a combination of threshold criteria, appears to significantly address the maneuver synchronization bandwidth challenge for distinctly different maneuver primitives of sprint, terrain following, and echelon turns. However, this 50% reduction in individual vehicle maneuver synchronization bandwidth might not be adequate for future tactical bandwidth constraints between training vehicles. The bandwidth problem is compounded when multiple training vehicles are sending control updates if a “many to many” vehicle update solution is implemented. Also, surges of up to 20 meter differences in live versus SPM clone positioning might not be adequate for specific training needs. Future research should be conducted to address the above remaining SPM issues and enhance promising SPM Phase 2 experimental results.

FUTURE RESEARCH

Whereas SPM Phase 1 and 2 research investigated vehicle level synchronization prototypes using ModSAF baseline libraries, SPM Phase 3 is planned to extend this research to unit formation synchronization using a prototype Unit Control Language (UCL) and to develop an embedded SPM SAF testbed tailored for the INVEST program. The UCL investigation addresses the bandwidth problem of “many to many” synchronization updates between training vehicles. It aims to identify “unit controller to many vehicle” synchronization update techniques and do smaller, less frequent unit updates enabling even more efficient SPM performance. Such SPM models will take advantage of unit maneuver consistencies, and the mission, enemy, terrain, and friendly troops information available before and during training execution. Requirements development and a prototype testbed implementation of an Embedded SPM SAF system will be conducted, including PVD, network, and terrain interfaces.

Exit criteria goals of this future research are 1) implementation and bandwidth investigation of a Unit Control Language (UCL) with simple platoon movements and formations and 2) demonstration and investigation of an operational SPM SAF prototype, including a high resolution terrain database interface. These results are hoped to further reduce bandwidth from the Phase 2 ModSAF baseline and feed promising simulation concepts into the future INVEST embedded SAF system.

ACKNOWLEDGEMENTS

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