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White Cell Networking

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As part of the Department of Defense (DoD) Research and Development (R&D) process, new technologies must be tested and evaluated in increasingly real world and operationally relevant environments as the technology matures and approaches a transition point. Many sponsors will coordinate integration with existing military war-game exercises. These events provide a researcher with the opportunity to experiment with real-world noise, to understand the operational needs their technology will fill, and to demonstrate their technology to transition partners. Participation in these events involves additional responsibilities beyond those in laboratory-bound and isolated experiments. Researchers will embed with the force and must supply operationally relevant data. They must must communicate with the so-called "white cell" in order to provide a Common Operating Picture (COP) overview with force perception to the event's audience as well as for persisting data useful to those performers that operate on force-level geo-spatial and temporal data.

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EXECUTIVE SUMMARY

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WHITE CELL NETWORKING

1. INTRODUCTION

As Research and Development (R&D) technology improves and is ready for experimentation outside of the lab, it must be tested in increasingly strenuous, real world, conditions. This will ensure the platforms are robust to noise and environmental factors that are managed in laboratory environments. However, organizing a controlled real world experiment for a single platform can be costly. In addition, no research platform is ever intended to be transitioned to the fleet in i solation. It will need to integrate with the existing technologies. It will need to transmit its collected data to existing software, and may even be required to coordinate with other platforms built by different organizations.

One approach to this is to hold integration events with multiple performers, held in semi-controlled environments, for example on military test ranges. Technologies at multiple levels of readiness can be brought to these events, even those still in very early stages. The performers would use this time to deploy their technology, collect data, and provide that data to other performers as necessary. But rather than an unorganized hodgepodge of platforms operating in isolation, these events can be built around a common theme, providing the performers with a realistic goal with measurable success.

In order to evaluate the individual systems and more importantly, how their integration benefits the overall goals of the force, we need to observe all aspects of the system from a common location. One approach is to aggregate all of the collected and time-stamped data after the event and create a forensic, post-mission view of the event. One drawback of this approach is that, due to the distributed nature of the systems, the timestamps may not synchronize correctly. This presents a challenge when attempting to determine cause and effect. More importantly, however, is the time delay between when the data is collected and when meaningful results can be extracted from it. Many performers are focused on their individual platforms, not on the overall mission objective, for which their platform provides one piece of the larger perspective. Without real-time analysis, many issues would go unnoticed and unaddressed.

For this reason, it is vital to integrate all data at a common location independent of the experimentation performers. Aggregating all data at a so-called white cell allows for real-time analysis of the event. It allows performers to view how their systems are contributing to the larger force objective. It allows sponsors to evaluate new technologies in a more realistic situation, rather than in highly controlled laboratory environments, in isolation from the targeted end users.

This aggregation comes at a price, however. In addition to the straightforward integration between the platform and a force unit, the performer also has to integrate with the white cell. For platforms with limited resources, this additional requirement may place too large of a burden, distracting from the higher priority goal of evaluating and improving their platform and integrating the platform with the force. Not all collected data is valuable in its raw form, which alleviates some of this burden, yet all platforms need to collect localization information so that its position can be shown at the white cell. Yet not all devices need a discrete

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GPS receiver, and adding one may increase the cost of the platform, and for systems with weight or space restrictions, may prevent the correct operation of the platform.

Not all data is generated by discrete platforms. Some systems accompany the force and perform analysis on the incoming raw data. The results of this analysis should be exposed to the white cell so that reviewers can anticipate the decisions made by the units. However, transmitting this data could have a negative impact. If the unit is attempting to remain invisible in the IR spectrum, it is not able to use the easiest communication methods. Some data, such as real-time video, cannot be sent because the bandwidth required would cause degradation of the system's performance.

NRL has attended many of these experimentation and integration events, establishing the white-cell to provide the common operating picture for each. In doing so, we have worked with most of the events' performers in order to best integrate their technology into the white cell. This paper details our experience. We describe the events and justify the need for a white cell. We detail the methods used to integrate each component along with pros and cons for each method. We discuss the integration at the white cell, including how to accept, store, and visualize the flood of incoming data. Finally, we provide a set of recommendations to improve future integrations.

2. BACKGROUND

With rapid transition being the goal for new technologies, early integration can ensure that performers are developing towards a realistic and useful target. Integration events provide the opportunities to see how the force might utilize a new technology and where it fits into existing Standard Operating Procedures (SOPs), allowing for early direction changes. They give leadership the ability to envision the next generation of SOPs. Finally, they provide the opportunity to collect a large amount of data for post-processing. This data can be used by other performers, for example, path-planning algorithms for autonomous systems, or by sponsors planning the next event to address issues discovered during review. These events are expensive, on top of the expense related to developing the technology in the first place. It's important to capitalize on this aggregation of common interests, to generate value beyond those obtained by the performer for the performer.

This paper focuses on a common event scenario: force-on-force. In this approach, the performers and their technology are divided into two teams. One force is the aggressor and the other is the defender, respectively the red force and blue force. The red force will primarily consist of mobile platforms, for example, conducting recon and Intelligence Preparation of the Operational Environment (IPOE), or to deliver a payload. The blue force will contain a mixture of static and mobile assets providing perimeter surveillance and defense. These events can be entirely composed of autonomous platforms or could be used by actual military forces participating in these scenarios.

These events are designed purposely so that the performers are able to collect the information they need. An explosives detecting Ground Penetrating Radar (GPR) platform will traverse a path with manually placed mine-like objects whose positions are precisely recorded. The image processing algorithms will be given positive hits in the form of neutral confusers, even if the red force is unable to field their platforms. The force-on-force scenarios, while important, are secondary to the performers actually collecting useful data to improve their systems.

In addition to the "red" or "blue" force in these events, there exists a neutral "white" entity that maintains full battle-space awareness. This is contrasted with the red- and blue-cells, which collects data from their platforms and maintains a knowledge state for each team's assets along with detections and belief states over the opposing team. Having a white cell integrated with both teams is essential for several reasons. It allows for a Common Operating Picture (COP) view of the battle space. It allows for centralized recording of the data for later playback. It provides a common view from which all performers can prepare an After-action Report (AAR). Most importantly, it allows for an accurate assessment of the overall system's performance independent of any individual performer's report.

While a large portion of these events are spent integrating with other performers, collecting preliminary data, and fine tuning the technology, the event will culminate in a semi-scripted force-on-force live event. These are usually attended by distinguished visitors including the technology sponsor(s) and military leadership. It is important that they are able to see as much of the event as possible, even when the event's footprint is spread across a large area. These events are very dynamic, and it is not possible to be embedded with each performer without missing out on other technology. A similar problem is adjudication. The safety of embedded human assets is of primary importance. Any actuators that could cause harm are disabled, therefore, the effects of actions must be refereed by a neutral party. In order to provide real-time adjudication, real-time data needs to be available from both forces, without exposing one force's data to the other.

The white cell exists to bring as much of the battle-space together as possible for these purposes. Assuming a perfect world, all network traffic including raw sensor data would be routed to its intended destination within the force hierarchy, and additionally, would arrive at the white cell. Here, the sponsors could view the location of all assets on a map. They could see what intelligence each force is collecting about the other, and importantly, what intelligence gaps exist. They could see sensor feeds including Infrared (IR) detectors, GPR, Electronic Warfare (EW) signatures, and so on. They would be able to evaluate the experimental technology, not just as a stand-alone tool, but as it integrates with the force. Unfortunately, this is not a perfect world. Much of the communications resources are spoken for while performing their primary function, and adding additional communication would burden the network. High-data applications such as live video feeds either need to be excluded or would need to be transmitted over an unused medium.

Another valuable component of the white cell is data persistence. Some technologies operate on the data generated by other performers. For example, an image detection algorithm might process incoming video feeds, and a route planning algorithm might accept target obstructions such as underwater or land mines or enemy forces. While they are performing at the event, they will be executing their pre-trained models, however they can use the data captured during the event to further improve their models. While these performers can integrate directly with the data sources of interest and persist these feeds locally, they are only collecting a subset of the data, namely the video feeds or target calls. The data aggregated at the white cell will be much richer, including precise GPS readings for all moving targets. By having this data aggregated in one location, the event can be played back, with sensor readings injected into the network at precise timing, to allow for mixed reality evaluations, where only one component is being evaluated while the rest are all virtual. Further, if too many point-to-point integrations are taking place, the overhead can become a burden.

By not integrating with the white cell, performers are excluding their technology from presentation during the real-time event. They must demonstrate to their sponsor in isolation, before or after the event. For sponsors with many performers, the technology that isn't presented is the technology that is forgotten and eventually, no longer funded. Technologies that rely on the data generated by these poorly integrated platforms must be diligent about collecting it directly from the performer after the event, because it will not be available elsewhere.

While the white cell is a critical component of these events, it does introduce its own limitations and constraints. The most important is that the white cell must not affect the normal function of the performers. Primarily, it should not reduce the communication bandwidth since this would degrade the technology under evaluation. It should also not allow any bleed-over. It is collecting data from both red and blue forces, therefore care must be taken to ensure the white cell does not transmit any of that data back out, otherwise the opposing forces would have unfair view of the other force.

Another major constraint is continued operations within the event configuration, for example, Global Positioning System (GPS) denial, communications jamming, EW for force detection, or night operations. GPS jamming disables the devices' access to localization information, resulting in erroneous data being sent to the white cell. Similarly, communications jamming will prevent the force from communicating as well as interrupting white cell information flow. When EW techniques are being employed to locate enemy forces, a loud spectrum solely for communicating with the white cell will give away a unit's location, even if all other communications are quiet.

It is important to plan for these event constraints early. For example, when jamming is employed, platforms could choose to transmit white cell data over a medium not subject to jamming. This choice will come with its own pros and cons, for example requiring additional hardware on a platform that is already weight or power constrained. By the time the event has started, if a plan to work around these constraints is not in place, it's usually too late.

Section 3 discusses the various methods for integrating with the white cell and provides some considerations to assist with choosing the most appropriate method. Note that a choice for one event may not be the best choice for another. The goal is to provide the maximum level of awareness to a central point for monitoring and evaluation, and later, for post-event processing. Having this integration is nearly critical from a system's evaluation perspective, however the higher priority constraint remains that the normal operation of the event not be disrupted.

To that end, the white-cell network does not need to represent any real world network. It is not a proxy for anything employed outside of an event. Therefore, it is not critical that the white-cell network be rigorously engineered. It is expected that integration will be "monkey-patched" together. White-cell integration is typically performed ad-hoc and last-minute, however, this does not obviate the need for planning. When too much liberty is taken, last-minute becomes too late, and the integration does not occur. Therefore, it is important to be prepared to integrate, to be aware of alternate options in case the preferred approach does not work, and to communicate with the white cell engineers in advance of the event so that integration in the field can be as smooth as possible.

3. INTEGRATION TECHNIQUES

There are multiple avenues for transmitting the necessary data to the white cell. The most common are shown in Table 1 and discussed further in this section. Other approaches not covered here are certainly possible. For example, an underwater platform might communicate via acoustics. We do not consider this case because of the low-bandwidth associated with underwater acoustic communications. In this case, we might assume that the platform will integrate with another system more suitable for transmitting to the white cell using one of the techniques discussed here. The key takeaway, however, is that any approach that gets the job done should be on the table. Successful integration with the white cell is not predicated on the use of best practices. Each event's integration could be an ad-hoc, one-off solution, so speed of integration takes priority over beauty. For the underwater acoustic example, if the platform is sending position data and the white-cell is located near the water, it may make the most sense to plug an acoustic receiver into a computer and drop the microphone into the water.

Name	**Pros**	**Cons**
Government Resources	Easy to deconflict	Varying throughput; not be as reliable in international operations
Operation Equipment / Green Gear	The equipment is already in use	May reduce bandwidth available to normal operations
Pre-existing infrastructure	Potentially high throughput (e.g. fiber-optic cable); does not impact event behavior	Not always available; unable to modify
Point-to-Point	Decent throughput; not subject to jamming	Beholden to Line of Sight (LoS); detectable in certain situations; cost prohibitive; difficult to stand up
Sneakernet	Very high bandwidth	Very high latency
Dirty Internet (LTE, Wi-Fi, Satcomms)	High throughput; large coverage; does not impact event bandwidth	Easy to detect using EW

Table 1— A list of the most common integration techniques along with general pros and cons for choosing each option. See the text for a more complete review.

3.1 Government Resources

Government Resources operate within the domain of reserved frequencies (TODO: list these?). Depending on the integration event, DoD scientists may be able to request a portion of this spectrum for force integration or white cell adjudication and data collection. This allows for a communication layer that will not be affected by off-the-shelf equipment within the event (due to laws set by the FCC). This can reduce the risk of unexpected communications interruption, however spectrum deconfliction within the event is still necessary. Multiple performers cannot transmit on the same frequency simultaneously, the same as with the public spectrum. Furthermore, if another performer or a force within the event has already claimed a frequency, another must be chosen, which can have bandwidth limitations as the reserved frequencies have varying throughput. Another consideration is that operating within these frequencies is considered "loud" from a spectrum analysis perspective. A transmitter may detected and located with spectrometers. If the goal of a vignette is to remain undetected, this approach may not be appropriate. If these tools are only used for white cell communications, then all participants may agree to ignore these. This may cause other problems however, as these communications may interfere with other performers developing spectrum analysis tools. A final consideration is that this spectrum may not be reserved outside of the U.S. If this equipment is deployed at an international integration event, this spectrum becomes subject to local regulations.

3.2 Green Gear

Operational equipment, or "Green Gear" refers to the hardware that an operational military unit already has as part of standard gear. Examples include L3 Harris radios, PRC-117G MUOS radios, MPU5, and Silvus. These operate on a variety of frequencies with associated bandwidths. This infrastructure is used to report force movement within the command structure. By integrating with the existing network at this layer, we can ensure the collected data is routed to the white cell as a byproduct of correct network operation. Integration is typically not a heavy lift. It is possible to integrate using Ethernet. However, these options typically have limited bandwidth. They are used primarily for command structure communications, and as such, we cannot saturate the channel with sensor data without risking the normal operations of these networks. The white cell is responsible for capturing all data for post-event replay, which includes aggregate sensor readings, however green gear is not the ideal solution for this. It may be used to transmit small messages such as detections or telemetry, but raw sensor feeds would overwhelm it. It is still important that this data arrive at the white cell though. If it is not useful in real-time, for example if it is not human consumable, a delayed arrival including via sneakernet may be acceptable. Otherwise, it may be wise to consider an alternate high-bandwidth option. As a final consideration, these systems also operate on restricted frequencies and cannot be operated without prior FCC approval, which will limit testing in laboratory spaces.

3.3 Pre-existing Infrastructure

Pre-existing infrastructure at the event site is a valuable option for passing data without impacting the bounds of the event since this infrastructure is considered outside the event‘s bounds. Typically this will be underground data lines between buildings at the host facility. Using this infrastructure allows a high amount of throughput between locations, without creating any wireless footprint. This also has the added benefit of not impacting the behavior of the event, as many on-site events are not necessarily leveraging local networks for communication or integration. It serves as a background, unseen method of transmitting data that is not necessary for the event's success, which is the primary goal. The downside is the limited availability at a given test site. Some sites may not have any infrastructure, others may be too large to justify it, and still others may not make it available during a particular event. The on-site facilities may be fully utilizing the resources or may be leery of having third parties operating within their network. Additionally, the actual access point of this resource may be challenging to tie into, for example if the performer or white cell are not located near the access point. Finally, when relying on existing infrastructure, the event participants generally have no say for how the network is configured. Performers are subject to the infrastructure as it exists. It is generally impossible to create a layer 3 infrastructure if the site only has layer 2, or to attempt to bridge disparate networks together.

3.4 Point-to-point

Point-to-Point based communication equipment refers to sensors that maintain a line-of-sight connection between each other, for example using IR, UV, or even visible light, or directional radio antennas. This allows the transmission of data from one point to another, effectively creating a layer 2 network connection between the two sites. This resource can be invaluable when attempting to get static "last mile comms" from one location to a white cell hub. Generally, there are no worries of a detectable RF footprint unless the signal is subject to scattering, for example, a laser becoming visible in fog. It is also robust against any other form of Recon/Counter-Recon actions as it relates to wireless communications such as jamming, spoofing, interdicting, catching data, etc. These assets also tend to be high throughput depending on the spectrum, on the order of tens of Gb/s. While these resources are quite appealing in that they do not impact the assets being tested, there are a few considerations limiting this technology‘s use. First and foremost, these technologies are expensive compared to most options. Two devices are required, for which we were quoted $25k (TODO: we should probably cite this or be less specific). Additionally, you are required to maintain a line of sight between communicating nodes. Since the directed devices operate on a narrow cone, it can be a challenge to focus and configure the equipment. Further, these two communications components must be static. Attempting to use them on a mobile platform or traveling with a mobile force and regularly stood up and torn down, requires an inordinate amount of configuration, to the point that the white cell integration will dominate the performer's time at the event. Lastly, while this method is discrete compared to others, it is not fool-proof. Optical point-to-point communications can sometimes be detected by Night Vision Goggles (NVGs). The narrow spread of the transmission used by these tools does mitigate this, however once detected, NVG users can pinpoint the assets' locations.

3.5 Sneakernet

The "sneakernet" method of integration should be the least preferred method due to its high latency. It is the last-ditch method and should be employed only when no other option makes sense given the constraints of a particular event. As the name suggests, this method involves physically transporting (via a runner wearing sneakers) data from the platform to the white cell. To send data via the sneakernet, the data must be moved from the device to a physical medium such as a hard drive, flash drive, or CD-ROM. This may require that the experimental device return to base after completing a mission so that the onboard storage can be accessed. The transfer medium must be transported to the white cell, which may not be near the performer's area of operations. Some events may cover a very wide area or may be distributed among several sites. It is generally a good idea to consolidate and transfer as much data as possible per trip. Once the data arrives at the white cell, it must be injected into the system. By this time, the event has usually concluded, so the only value of this data is for post-event processing, although it may sometimes be appropriate to use it as mock real-time data for a subsequent run of the vignette, especially for newer technologies.

3.6 Dirty Internet

When all else fails, we can consider that the data transmitted to the white cell need not arrive using approaches only available in real world mission scenarios. Although a squad can only communicate with its platoon through equipment that will be available during a conflict, nothing prevents the white cell data from routing through another path. For example, the squad may be operating dark and is therefore unable to communicate with the platoon. If we were relying on that connection to proxy data to the white cell, then unable from the squad would not arrive. However, if the squad had a cellular device or a satellite receiver with connection to the internet, it could use this as a means of communicating with the white cell. It would not use this to communicate with the platoon, even if such a connection existed. This connection is dedicated for white cell communication under the assumption that the dirty internet connection is not available between the squad and platoon in this simulated scenario.

Careful consideration must be taken when using this method. We have called this the "dirty" internet because it falls outside of the pristine event conditions. It is subject to bad actors not scripted into the event, and mitigation techniques must be employed to ensure that outside forces are unable to reach into the event's network. This is largely mitigated by having no open ports accepting connections, including at the white cell. However, if the white cell is not open for connections, how does it receive data? One option is to establish a secure Virtual Private Network (VPN) at a location outside of the event. Both the performer and the white cell would connect through this and then communicate within this network, ideally by means of a server within the VPN that can ensure only valid devices are connected.

While this is a powerful technique, it does come with some restrictions. The performer must have a strong connection. This may not always exist in some of the more remote areas. They must bring an access point, which may not be reasonable for platforms with weight or power restrictions. Satellite communications are typically much larger and more expensive compared to a Wi-Fi hotspot. Finally, they must be configured to connect to the VPN. This is usually something that needs to be arranged beforehand as it is complex enough that it shouldn't be attempted at the start of an event. A final consideration is the classification of the data collected. Most experimental data is unclassified, however if this is not the case, then this option would not be available.

4. INTEGRATION AT THE WHITE CELL

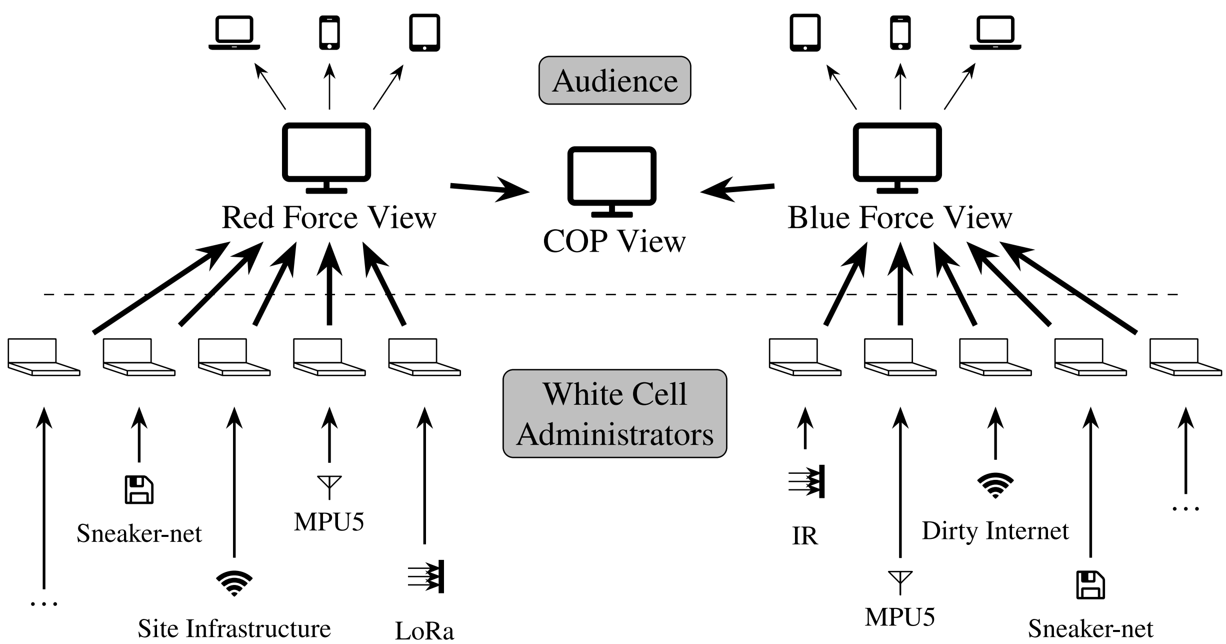

Fig. 1— The physical structure of the white cell. Audience members view the COP along with the red and blue force belief states including any squad level views. The white cell administrators operate behind the scenes ensuring data is flowing from the individual performers to their respective COP views.

4.1 Physical Resources

The white cell represents a single location, but it is typically not a single workstation. The actual configuration will vary depending on the needs of the event scenario. It will include communications infrastructure to support each of the performer integration techniques described in the previous section. A minimal setup would consist of three workstations, one for red force visualization, one for blue force, and one aggregated view of both forces. The force visualization systems can serve as the primary integration points for their respective forces, however issues in any of the incoming data feeds or processing thereof could result in the entire system crashing. In addition to adding stability, separating the incoming feeds can serve to simplify data aggregation and persistence. For example, if a platform is transmitting live video feed, it is better to have a dedicated workstation receiving that feed and storing it locally, separate from the workstation responsible for visualizing the platforms' positions and automated detections. The terminal workstation would then only be responsible for video playback on demand, and any dropped frames will result in degraded real-time viewing without incurring any data loss. More elaborate configurations are possible as well, including tablets, cell-phones, or VR headsets as visualization tools. Ideally these should be separate from the systems that collect, persist, and serve the data.

The red and blue visualization workstations are intended to show the full state of that force's knowledge state, including detections of the opposing force. These detections will likely be inaccurate or noisy; they are taken from remote sensors or are manually entered by a human operator. Since a given force does not have access to the other's ground truth, the difference between the detection and actual position of an adversary can be useful in evaluating the performance of a system being investigated.

These integration points should not transmit outside of the white cell since they are not technically a part of the event, however it may be necessary to send control messages. For example, the white cell may need to request that a platform reduce the amount of data that it is transmitting or otherwise adjust resource usage to ensure the white-cell network continues operating without interfering with the event.

The red and blue visualization workstations display their respective forces' data feeds, and in addition, they transmit data to the third workstation, which visualizes both forces. This is tricky because from each force's perspective, they are blue (friendly) while the opposing force is red (hostile). During the event scenario construction, the distinction is made between the two. Typically blue is assigned to the defending force and red is assigned to the aggressor. When aggregating this into a common operating picture, the red force data must be inverted so the two can be distinguished. Given the various data formats in use, this can be challenging, however typical messages sent to this white-force workstation have been converted to a common format, Cursor on Target (COT) for example, which simplifies this task.

In addition to the three workstations (or workstation clusters), the white cell must contain all networking infrastructure to receive data from the respective forces. This includes access to the dirty internet, Wi-Fi access points, MPU5 radios, LoRa receivers, and so on. If performers are transmitting data over the dirty internet, one white cell receiving workstation must be able to reach the outside network. If transmitting over green gear, at least one radio receiver must be co-located with the workstation. If both red-force and blue-force are using a light-based point-to-point option, then at least two receivers must be set up. All of these incoming data feeds must be connected using network switches so the data can be routed to the receiving machines. Managing all of this gear is non-trivial both from a physical perspective as well as a network and spectrum management perspective.

This is where planning becomes a major factor in the success of the white cell. If a force does not use a given medium, for example, if no platforms for the blue force transmit to the white cell using light-based comms, the blue force visualization station will not be connected to an IR receiver. It may not be unpacked, and it may even not be included with the equipment brought to the field. However, if a performer decides mid-way during the event setup that the only means of transmitting to the white cell is through IR, then changes to the physical setup at the white cell must be made. Equipment must be unpacked, space must be allocated, and cables must be added. If too many last-minute changes are made like this, the white cell administrators may be unable to manage the incoming feeds that are properly integrated. However, if this scenario had included the use of IR as a backup plan, the white cell management team would be prepared to implement that solution as necessary. The time needed to make the change is not the only consideration. The physical hardware available is a limiting factor as well. If all of the IR equipment has been allocated before the performer realized it would be necessary, there's not much that can be done.

In addition to hardware constraints, we have to consider the spectrum constraints. Bandwidth is not infinite. If too many performers attempt to use the same medium, they run the risk of saturating the spectrum, preventing others from transmitting. Careful consideration must be given to allocating the bandwidth. While it is important to get as much data to the white cell as possible, this must not be taken to an extreme. Video streams can provide the viewing audience a visceral sense of the system's capabilities, but if other platforms only need to transmit localization and small telemetry messages and are unable to connect, the global view of the event will be flawed. If too many platforms are attempting to stream video, none of the video feeds will arrive intact, and the audience will be left with an interminable buffering screen. While this self-inflicted Denial of Service (DOS) attack is bad for the white cell, it is unacceptable if the medium is also used for the event itself. For example, if a blue force squad regularly sends position information to the platoon over green gear and reuses that signal to transmit video data to the white cell, then the messages sent up the chain of command could arrive late, or get dropped altogether.

Similar to spectrum setup is a concern for allocating network subnets. This is a problem not just for the white cell, but for any type of event relying on networking to integrate multiple performers. In the lab, it is not unusual to assign devices an IP address from the default space. This is typically `192.168.1.x` or `10.0.0.x`. The problem then, when the platforms are deployed in the field, is that multiple groups will be using the same subnet. This may be fine, for example, if they use this subnet without plugging into a larger network, but this is rarely the case. Once this network is attached to a common switch with a network that also assigns IP addresses from the default subnet, chaos will ensue. It is imperative that performers plan for this, communicating with the network engineers to have a subnet allocated for their use. In the best case, performers will design their systems to be agnostic to the subnet, allowing it to be assigned last-minute. This provides the most flexibility both to the performer and to the network engineers, who may need to accommodate early-stage performers who have their IP space hard-coded on their proof-of-concept devices.

4.2 Personnel Resources

In addition to the hardware—the computers, networking relays, and cables—the white cell will contain a large number of people with varying backgrounds, and here as well, planning is critical to ensure smooth operation. The white cell is intended as the primary overview of the event, the single source of truth. It is the briefing backdrop, where each group's representative presents their technology within the context of the larger mission. Program managers are present to participate in these briefings and observe the technology outside of the laboratory environment. In addition, they expect to see their sponsored technologies interacting with those from other program managers. Subject Matter Experts (SMEs) and warfighters are on hand to discuss their experience relevant to the technologies being demonstrated. Finally, this is a force-on-force scenario and as such, must be adjudicated. Referees will be deployed in the field alongside the forces as well as in the white cell where the full picture is available.

This group of human assets is not static; people come and go throughout the event. Performers, having presented their briefing, return to monitor their platforms in person. Program management can visit their sponsored performers for in-depth reviews. Representatives from other **DOD!** (**DOD!**) agencies attend in order to keep abreast of what technology is being developed in their respective area of expertise. During this, white-cell technicians must be on hand, monitoring the systems, verifying that the various network feeds are still coming in as expected and the receiving systems are still up and handling requests. With all of this human capital in one place, the white-cell can become crowded and even dangerous if not handled correctly.

Typical event planning will establish a briefing area early on. The choice for this location will be driven by several factors, including access to parking while respecting the event bounds. Unfortunately, this does not take into consideration the white-cell needs, including line-of-sight communication. Therefore, it is crucial for white-cell technicians to have an early active role in planning. The layout for the white cell should include two distinct areas with a clear delineation between briefing and operational areas. Ideally, this should be housed in two adjoining rooms or tents. The three visualization systems should be housed in the briefing area and the rest of the hardware in the operational area. This minimizes the audience interaction with the supporting hardware and the technicians working to keep that hardware operating correctly.

5. TIMELINE

A significant amount of planning and coordination is necessary for a successful event. In this section, we describe the timeline of an event from the perspective of the performers and white cell engineers, focusing on the integration points, from the event's early planning to the after-action reporting. By understanding the timeline and event flow, a new performer can take care of tasks that should be addressed ahead of time so that the time spent in the field can be spent on those tasks necessary for a successful integration.

5.1 Event Planning

Event planning begins very early. For some events, this happens during the after-action stage of the previous event, when the issues encountered are still fresh in everyone‘s mind. Decisions are made and documented, and these will serve as the basis for the next event's planning. Active event planning begins weeks or a few months before the event, depending on the event's size. During this stage, the list of participating performers is finalized. The event footprint is established including the force positions, briefing and white-cell site, and flight ceilings, from which, the event scenario is built. Performers are assigned to red or blue force depending on where their technology is best suited.

As the details become more concrete, the performer and white cell administrators must begin discussing integration, negotiating the last mile communications necessary to reach the white cell, including a preferred approach and a backup plan. It's not always possible to fully implement the integration at this point. The performer may not have access to the receiving endpoints or may not have the equipment needed, however some effort should be put in to stub out the connections. This could include adding a thread to the software stack that attempts to publish messages over a currently null connection, or it could be adding a receiver to the messaging queue that will eventually forward messages. Thought should be given to message formats. If the white cell is required to decode a custom or proprietary message format, then libraries and Interface Design Descriptions (IDDs) need to be provided, and if the performer intends to perform the translation to a common format such as COT, then this code should be written and sample output sent to white cell engineers for validation.

During this phase, the white cell engineers will be in communication with all of the performers. In addition to assisting with initial integration plans, the engineers will be ensuring that the overall configuration makes sense. They will keep track of the bandwidth needs of each performer to ensure that the aggregate communication needs are within reason. Just as importantly, the white cell administrators will be actively

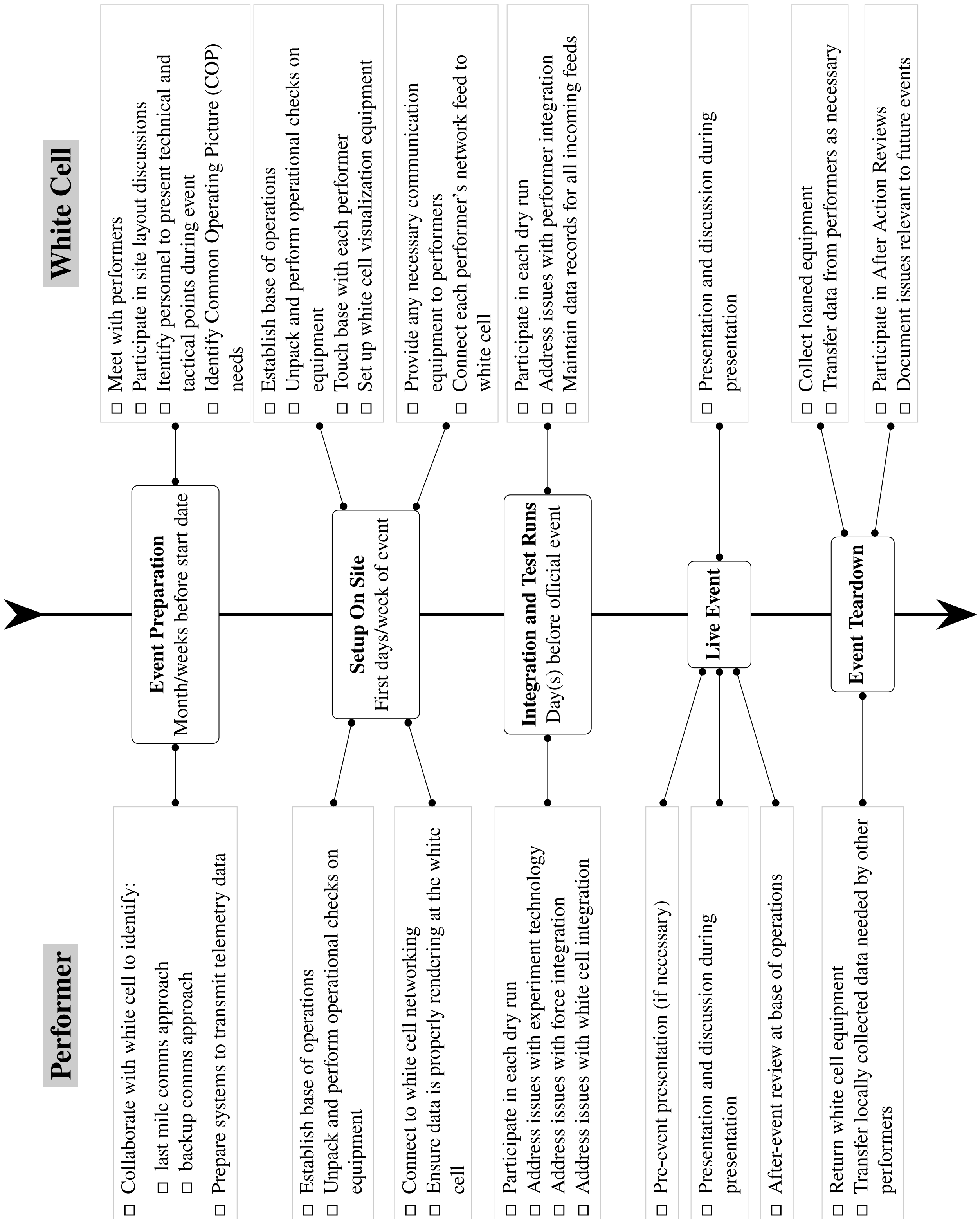

Fig. 2— Event timeline from event planning at the top to event cleanup at the bottom. Performer responsibilities are listed on the left, and white cell administrator responsibilities are listed on the right.

participating in site configuration planning. If a performer has a particular networking need such as LoS, they will take this into consideration when selecting a location for the white cell. This is one key reason why early communication between the performers and white cell engineers is critical.

Finally, the white cell admins will begin mocking out a COP view based on the expected data, preparing the presentation narrative. Yet it‘s not on the white cell to develop this narrative; rather they are only assembling the performers' feedback and their respective sponsors' expectations, ensuring that the visualization conveys the desired story. It is still the performers' responsibility to present the material. Because of the audience's size, the number of personnel from each group should be limited, ideally to a single SME. As the details of the event become finalized, discussions should begin on when and how a group's presentation should be scheduled to ensure the COP is presenting relevant real-time information.

5.2 Setup of Event on Location

Several days are allocated for setup. This may be a day or two for a small-scope event, or a whole week for an event with a large footprint and many performers. During this time, only the performers are at the event site; the sponsors and audience are not in attendance. After taking a tour of the site and facilities, performers will select a base of operations and begin to set up. They will set up tents, tables, generators, trailers, and field workshops as necessary. They will unpack their equipment and check it for basic operation, ensuring that nothing was damaged in transit.

Meanwhile, the white cell engineers will be performing similar tasking. During the event planning, they will have established a baseline understanding of which performers will be in attendance, what their anticipated hardware needs are, and how much time they need for their own setup before considering integration. They will unpack and set up this equipment along with all the equipment needed for the COP view. They will assist with finalizing personnel assignments for event adjudication and technical presentations. Finally, they will visit with each performer to verify the initial integration plan still holds. At this early setup stage, this may seem intrusive; the performer is more concerned with setting up and testing their equipment. They get no value from the event if their equipment is not working. Yet this is a crucial step. It enables the white cell engineers to ensure most of the work is already in place, so that once the performer is ready, integration is seamless. For example, if the initial plan had included LoS communications made impossible by the actual field conditions, then the changes need to be made at this early stage, while the performers are still setting up.

After the basic tests, the performer will eventually begin to run actual experiments. What this entails will be different for each piece of equipment, however this is the phase of the event that is most immediately beneficial to the performer, where they get the actual real world data with ground truth. The later demonstration, fully integrated with the rest of the event participants, is important for programmatic reasons: it demonstrates the return on research investment dollars. But to the researcher, the most important thing is operating their equipment and collecting the data that can drive future work back at the lab.

Once the performer is collecting data, they should work with a white cell engineer to begin integrating. If all the preliminary work has been done, this is a simple step. In practice, there will be issues to iron out, however the major hurdles should have been overcome during planning.

Once the data is flowing to the white cell, the engineers will ensure it is arriving correctly landing workstation as well as flowing through the system to the COP. Issues that can arise here include hardware problems such as a faulty switch, disconnected cable, or LoS interruption; data format discrepancies such as one component using an outdated version of a message schema; or an unintentional DOS if one performer uses a communication medium for local communication that prevents concurrent use for white cell traffic.

One non-obvious and otherwise trivial challenge is that the white cell can only debug issues when the performer is transmitting data. If a performer has successfully integrated but temporarily stopped transmitting, e.g., to perform some maintenance, then a white cell engineer may treat this as a failure and waste time hunting a faulty connection. This demonstrates the need for active dialog between the performer and integration partners.

5.3 Integration Practice Runs

After the integration period, the event coordinators will begin executing the force-on-force scenario. This will give the performers a meaningful goal for their testing, and it will help to ensure everything is properly integrated. It almost never is, which is fine. At this stage of the integration, not all performers may even have their equipment fully set up. By participating, it's possible to discover issues that might not be apparent by exercising a piece of equipment in isolation. These practice runs are repeated multiple times, getting closer to perfect each time. White cell will record all incoming data for each vignette so that it can be played back in the COP, to identify shortcomings that need to be addressed in the next dry run. The goal is to perfect the processes so that the live event is flawless.

During this phase, performers and white cell administrators are ironing out any issues. The actual work is highly dependent on the types of issues that arise. If the preferred integration solution is performing poorly, they may preemptively install the backup option. If a particular medium or set of frequencies begins performing poorly during the event, then the engineers can look for sources of saturation. If data is arriving but not properly rendering in the COP, then the performer and white cell engineers will investigate and resolve these problems. On the rare off-chance that no issues come up, everyone can focus on the lagniappe, those features that would be nice to have, but which are not critical for event success, for example, a live feed that requires extra hardware to transmit but is otherwise machine processed and not necessary for the COP view.

5.4 Live Event for Audience

Most of the lead-up to the live event is only loosely scheduled. Each performer and technology will have different requirements; some performers may even arrive relatively late if their equipment and connection requirements are minimal. The live event, on the other hand, must adhere to a strict timeline due to the vast influx of people. A typical agenda will include arrival times, a timebox for preliminary presentations, an event start time with inline presentations as necessary to explain tactical implications. The remainder of the day is open for audience members to visit the individual performers and get a closer look at the technology. During the live event, white cell will record all incoming data.

5.5 Event Tear-down

Once the final event has concluded and the audience has dwindled, clean up and tear-down can begin. For some performers, this can be accomplished before the site closes for the day, although most will return the following day to finish packing up equipment. At this point, white cell admin will visit each performer and collect any loaned equipment. They will also attempt to collect any data that was generated locally but not transmitted to the white cell, however at this stage in the event timeline, everyone is too busy with tear-down to bother with this. This task typically gets dropped and is not picked up until much later, when the sponsors begin requesting it for their own purposes.

6. CONCLUSION

Participation in a Department of Defense (DoD) R&D integration event is an enriching experience. Performers are able to see their technology employed in real world scenarios to better understand the conditions the technology will be subjected to. They will be able to collect data that otherwise would be cost prohibitive. The environment will be "controlled", but not nearly as restricted as a laboratory environment.

On the other hand, participation becomes a team effort rather than an isolated platform operating in a university lab. The data collected should feed into the force's knowledge base, providing some valuable situational awareness, for example, positions of enemy forces or potential hazards. It must directly integrate with the force employing the technology. Yet simply performing is not quite enough. The platform needs to send information to the white cell so that its function and utility in the overall mission can be evaluated. The white cell is where the program sponsor will get their first view of the technology operating in the larger picture. It provides a real-time view of the capabilities as well as shortcomings.

It is imperative that performers are prepared to integrate. Since the white cell is only employed in these war-game scenarios, much less attention is given to building a strong white cell infrastructure. It is usually an ad hoc configuration established during the event setup, when performers are testing and validating their equipment, while integrating with the force they will be embedded with. The cost of integrating with the white cell is necessary and integral, but it should not take an inordinate amount of time or effort to integrate. For this reason, planning is essential. The white cell administrators are capable of fantastic last-minute feats of engineering, however being an add-on to the event, it is not funded as a full-fledged performer. Therefore, it is the performer's responsibility to prepare for integration before the event. White cell engineers will typically communicate with each performer in advance of the event, but the performer, who knows their technology best, will be responsible for identifying the integration technique most appropriate for their system.

By integrating at the white cell, many of the performer's responsibilities to their sponsor are already met. They can show their technology's reliability and accuracy. They can demonstrate the value provided by embedding with the force. They can demonstrate their technology's effectiveness in the face of adversarial conditions such as GPS denial. The performer can focus on collecting meaningful data that can be evaluated in the lab, rather than collecting data for their sponsor.

War-game scenarios with experimental technologies can be hectic, and nowhere is this more true than at the white cell. Every performer must tie into this cell, but the integration must be done in a way that does not affect the event. Data must not be transmitted from the white cell to the force, and the aggregation of data must not DOS the event. By cooperating with the white cell engineers, performers can benefit from the work and go directly to step three: profit.

7. ACRONYMS AND DEFINITIONS

AAR After-action Report

COT Cursor on Target

COP	Common Operating Picture
DoD	Department of Defense
DOS	Denial of Service
EW	Electronic Warfare
GPR	Ground Penetrating Radar
GPS	Global Positioning System
IDD	Interface Design Description
IPOE	Intelligence Preparation of the Operational Environment
IR	Infrared
LoS	Line of Sight
NVG	Night Vision Goggle
R&D	Research and Development
SME	Subject Matter Expert
SOP	Standard Operating Procedure
VPN	Virtual Private Network

Platform A delivery vehicle for a research technology, which may itself be a research technology

Vignette A stage of operations within a war game