# DARPA NETWORK CHALLENGE

## PROJECT REPORT

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## 1 INTRODUCTION

On December 5, 2009, the Defense Advanced Research Projects Agency (DARPA) Network Challenge conducted the DARPA Network Challenge (DNC), a social network mobilization experiment to identify distributed mobilization strategies and demonstrate how quickly a challenging geolocation problem could be solved by crowd-sourcing. Ten numbered, 8-foot, red balloons were simultaneously launched and moored in parks across the contiguous United States. The first person to report to DARPA the correct locations of all ten balloons was awarded a $40,000 prize. The event was announced by Dr. Regina E. Dugan, DARPA Director, in a speech on October 29, 2009 at the University of California, Los Angeles (UCLA), during a celebration of the 40th Anniversary of the Internet and the first remote log-in on the ARPANET.


**Figure 1: DARPA Network Challenge Balloon locations**

The geolocation of ten balloons in the United States (Figure 1) by conventional intelligence methods is considered by many to be intractable; one senior analyst at the National Geospatial-Intelligence Agency characterized the problem as "impossible". A distributed human sensor approach built around social networks (Figure 2) was recognized as a promising, non-conventional method of solving the problem, and the Network Challenge was designed to explore how quickly and effectively social networks could mobilize to solve the geo-location problem. The speed with which the Network Challenge was solved provides a quantitative measure for the effectiveness of emerging new forms of social media in mobilizing teams to solve an important problem.

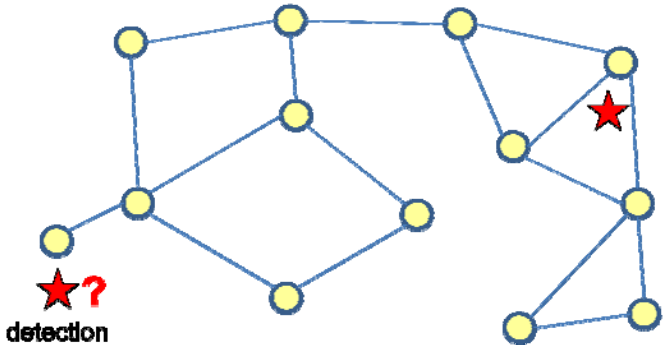


**Figure 2: Distributed Network Event Detection**

## 2 DARPA NETWORK CHALLENGE RESULTS AND ANALYSIS

Following the announcement of the Challenge, the DARPA Service Chiefs' Program (SCP) Fellows, a group of mid-career military officers from all the Services on a three-month tour at DARPA, monitored media outlets, the blogosphere, internet traffic and search trends, and team development to asses the diffusion of the Challenge. The SCP Fellows also met with several top University & Industry scientists doing research in the field of social network analysis. The objective of these meetings was to alert the researchers that a large scale experiment (a "stimulated epidemic" designed to actively influence the network) was planned should they wish to collect data and piggy-back on the experiment. The scientists included Dr. David Reed (MIT), Dr. Alex "Sandy" Pentland (MIT), Dr. Bruce Maggs (Duke University and Akamai), Dr. Jure Leskovec (Stanford), Dr. Carlos Guestrin (Carnegie Mellon University), and Dr. Chen-Nee Chuah (UC Davis).

Following the Challenge, the SCP Fellows conducted 53 interviews with individuals who competed in the Challenge. A complete list of the final team standings is tabulated in Appendix 1. The interviews were designed to assess diffusion of the Challenge, discuss team strategies, identify social and technical tools used by teams, estimate the network size, estimate mobilization speed, and identify social dynamic factors that were deemed important by the participating teams. The interview results were compiled and quantitative and qualitative comparisons between teams were made. Further details on selected teams are given in Section 3.

### 2.1 Observations on the Network Challenge Diffusion

The diffusion of the Challenge through mass media sources and social media channels provides a good comparison of the relative roles between traditional and social media methods for network mobilization. Some of the key diffusion events and dates for the DARPA Network Challenge follow:

29 Oct – Dr Dugan announces the DARPA Network Challenge at UCLA; DARPA issues press release to targeted media and bloggers

29 Oct – Huffington Post posts the DNC announcement (many of the initial citations for early blogs are linked back to the Huffington Post article)

31 Oct – MSSV posts very thoughtful and widely cited blog on the nature of the DNC and expected strategies for winning (http://mssv.net/2009/10/31/how-to-win-the-darpa-network-challenge/)

1 Nov – Slashdot posts DNC announcement (http://news.slashdot.org/story/09/11/02/0056236/Find-DARPAs-Balloons-Win-40K?art_pos=5)

2 Nov – Wiki tracking DNC teams is launched (http://redballoon.wikispaces.com/Groups)

4 Nov – Video of Dr. Regina E. Dugan's speech is available on YouTube (http://www.youtube.com/watch?v=N85ryOFVeQg)

13 Nov – DNC team SpotBigRed posts first video seeking team members (http://www.youtube.com/watch?v=0vz8ZI-8aXA&feature=response_watch)

Steady trickle of traffic to the DNC website, an average of 1000 new visitors daily

24 Nov – Registration for the DNC opens. DARPA_News tweets that registration is open

1 Dec – *New York Times* story runs (http://www.nytimes.com/2009/12/01/science/01darpa.html?_r=1)

1 Dec – MSNBC.com story runs (http://cosmiclog.msnbc.msn.com/archive/2009/12/01/2139419.aspx)

2 Dec – NPR's Here and Now broadcasts story on DNC. Includes interview with GA Tech Research Institute I Spay A Red Balloon team (http://www.hereandnow.org/2009/12/rundown-122-2/#3)

3 Dec – Rachel Maddow show broadcasts story on DNC (http://www.youtube.com/watch?v=4wyMB0gx_3Y#watch-main-area)

3 Dec – Team Farc announced (http://www.fark.com/cgi/comments.pl?IDLink=4816872) (Farc will become the #1 media referring site for web traffic)

3 Dec – MIT Media Lab team launches website and recursive recruiting emails

3 Dec – Nerdfighter team releases video blog (vlog) (http://nerdfighters.ning.com/profiles/blog/list?q=%2440%2C000+of+Red+Balloons)

4 Dec – DNC is the lead story on the CNN Tech page (http://www.cnn.com/2009/TECH/12/04/darpa.balloon.challenge/index.html)

4 Dec – Scientific American story runs (http://www.scientificamerican.com/article.cfm?id=darpa-network-challenge)

5 Dec – Balloons launched

5 Dec – CNN Headline News story runs, includes interview with the MIT Media Lab Team

Initial expectations that the DNC diffusion would progress virally were not realized until the final week before the balloon launch. This was the first week in December and corresponded with a *New York Times* Science section story. Prior to December 1, the DNC website had an average of approximately 1,000 new visitors everyday. The trend was steady following an expected initial spike after the original announcement on October 29. Traffic to the DNC

website increased significantly in the final week (increasing up to an average 20,000 visits a day) following the *Times* story and it is suggestive that a lot of the subsequent media coverage of the DNC in the final week were following the *Times* story. Several team efforts also went viral in the final days before the balloon launch including the Farc team and the Nerdfighters.

Two conclusions can be drawn from diffusion of the DARPA Network Challenge announcement. The first is that traditional, mass media is more predictable and reliable than viral diffusion for a given message. Mass media typically has a larger audience and better understood distribution channels. The fact that few products or companies have successful viral advertising campaigns relative to traditional advertising is most likely due to the same factors. The second conclusion is that viral diffusion, when it does occur, can be very rapid. The Nerdfighters list approximately 5,000 active followers of their regular vlog, but the Nerdfighter vlog announcing their DNC team had more than 90,000 views less than 24 hours after its release indicating that they had probably expanded beyond their traditional audience.

### 2.2 Identified Factors and Tools Affecting Team Performance

The following factors affected team performance in the DARPA Network Challenge, as determined from the post-Challenge interviews:

- Media coverage of the team
- Team built around an existing social network, or a social network constructed for the DNC
- Name recognition of the team (*e.g.* MIT Media Lab team and ISARB team associated with MIT & GA Tech respectively)
- Planning time available to organize the social network
- Method for searching Twitter posts for relevant DNC information
- Search engine ranking for the team
- Mobilization and dispatch ability of the team
- Team geographic coverage and density
- False report rejection strategy
- Mobile phone application available for team members
- Team overall strategy
- Team network hierarchy
- Trading / collaboration strategy with other teams
- Operations center for coordination, mobilization, tracking, and entry decision making

Eight distinct tools for the geo-location problem were identified from the post-Challenge interviews. Teams typically incorporated more than one of these tools into their overall gameplan.

- Marketing and media broadcast strategies to bring members to the team
- Recursive, incentivized recruiting of networks of friends and/or associates to build team
- Extraction of data of reported balloon locations from open internet sources (*e.g.* Twitter)
- Automated means of extracting data, *e.g.* Twitter crawler
- Deployment of technology with automatic reporting capability, *e.g.* iPhone applications

- Dispatching team members as spotters to search or confirm reports of balloons
- Website design that motivates, encourages recruitment, or allows easy, secure reporting
- Search engine rank optimization of website (some search engine algorithms weight higher links from media and .edu addresses to a particular website)

### 2.3 Network hierarchies for geo-location

The interviews revealed three general network hierarchies for the geo-location problem: mass broadcast, existing network, and recruited network. Network hierarchies are not mutually exclusive; indeed the most successful teams in the DARPA Network Challenge made use of all three hierarchies. The intent of the hierarchy definition is to identify the network models for the geo-location problem that are useful in understanding network structure and organization, and for classifying team strategies.

The mass broadcast hierarchy, Figure 3, seeks to both alert potential network nodes to the desired event detection and point reports of the event back to a particular node. The network saturation of the mass broadcast hierarchy depends on the extent of the broadcast and the effectiveness of the marketing. A search engine rank optimization strategy can increase the probability of a particular node receiving a detection report.

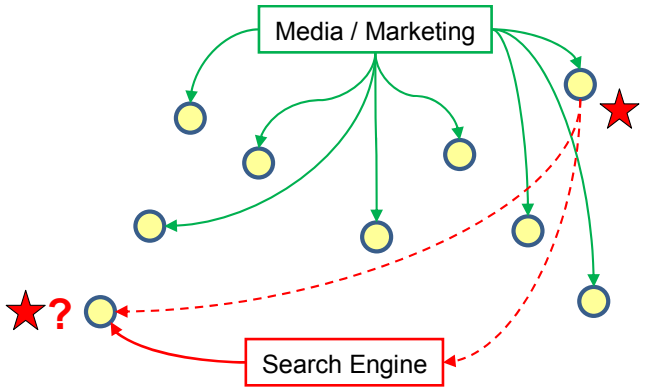


**Figure 3: Mass broadcast network hierarchy**

The existing network hierarchy leverages the scope and organization of pre-existing social networks, Figure 4. Since the network already exists, no time is necessary for network construction, but there may still be a delay in network mobilization for a particular task. In the DARPA Network Challenge, this delay was surprisingly small. There were multiple teams that successfully mobilized their existing social networks for the DNC with less than 24 hours notice. The existing network hierarchy also permits targeted mobilization for specific geographic areas if there is a database of node locations. This was also successfully demonstrated with impressive effectiveness by several teams in the DNC.

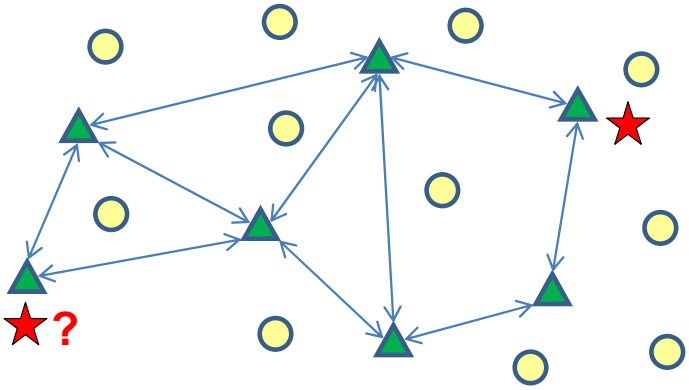


**Figure 4: Existing network hierarchy**

A network built through a chain recruitment of nodes, Figure 5, which in turn recruit nodes they are connected to, grows in a geometric sequence. If the recruitment at each stage is successfully transmitted to the subsequent layer of nodes, the overall network size will follow an exponential growth curve. The key to motivating each node to recruit its connected nodes is an incentive structure that is transferable through the network and which does not diminish with each layer. When a node is an individual person, a recruitment request to one's friends and associates to join a network is akin to an endorsement of the cause. This might limit or inhibit the recruitment growth if the cause is not perceived as worthy of the endorsement. The winning MIT Media Lab team built a network using a recursive incentive scheme that effectively recruited a large network in a short period of time. The game-like nature of the DNC and the low cost of participating were positive factors in the success of the recursive recruitment strategy for the DNC.

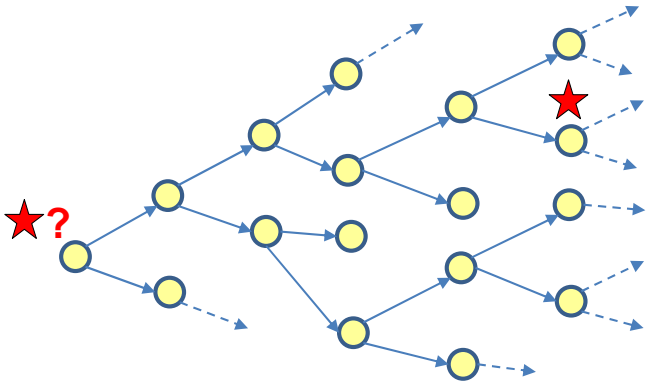


**Figure 5: Recruitment network hierarchy**

## 3 SELECTED TEAM SUMMARY

A total of 4,367 individuals registered in the DARPA Network Challenge. Because teams often had multiple registrants per team and because the DNC website did not require team affiliation to register, it is impossible to accurately extract the number distinct teams participating in the DNC. From the team interview data and from the 922 submissions to the DNC website, we can

conclude that there were at least 50 serious teams and perhaps as many as 100 teams that participated in the DNC. From the interview data and team estimates of network size, approximately 350,000 individuals participated in the DNC. The nature of the participation ranges from actively searching for balloons to merely knowing about the Challenge and being willing to report a balloon to a team. Some estimates from teams regarding network size yield passive DNC participant numbers in excess of 1 million. These higher estimates include anyone who was exposed to the DNC, *e.g.* by seeing a media report, who might then see a balloon and make the connection between the balloon and the Challenge.

The performance of twelve different teams in the DARPA Network Challenge is plotted in Figure 6 against the teams' mobilization time. The teams were selected as representative of the range of strategies, network hierarchies, and effectiveness. Not all teams that were interviewed are plotted in Figure 6 or discussed below in the team summary.

Figure 6 depicts relative comparisons of team network size, network coverage, and team strategy in the three outer wedges. Figure 6 also presents the correct number of balloon locations the team received through direct reports and the balloon locations that were extracted from the internet or through trades with other teams. The team network size is a quantitative size comparison between teams and is based on the team's estimate of the total number of active and passive members. The network coverage and team strategy wedges are qualitative comparisons between teams; the greater the radius of the wedge the higher the relative rating. Ratings were iteratively assessed by all ten SCP Fellows following all interviews to accurately reflect the relative strengths and weaknesses of each team. Specific examples and explanations are given in the team summary below.

The network coverage is an assessment of how much coverage the team received from media sources, the search engine ranking of the team, name recognition of the team, and the extent and geographic scope of coverage for teams based on existing networks. Coverage is distinct from network size. For example, both the MIT Media Lab team and the GTRI ISARB team enjoyed extensive media coverage (CNN and NPR respectively) as well as advantageous brand name recognition (MIT and GA Tech). The MIT team was featured in CNN Headline News reports on execution day which was more extensive than the NPR coverage of the GTRI effort earlier in the week. The MIT coverage wedge in Figure 6 is the largest followed by the GTRI team.

The assessment of the team strategy accounts for the overall strategy the team planned (execution of the strategy was not evaluated), the planned network hierarchy, filtering tools for false report rejection, mobilization ability, deployment of mobile phone applications, and the existence of an operations center. The MIT team received recognition for their recursive incentive recruitment strategy; whereas the Groundspeak and Nerdfighter teams received recognition of their large existing networks which they effectively mobilized including targeted dispatching from an operations center.

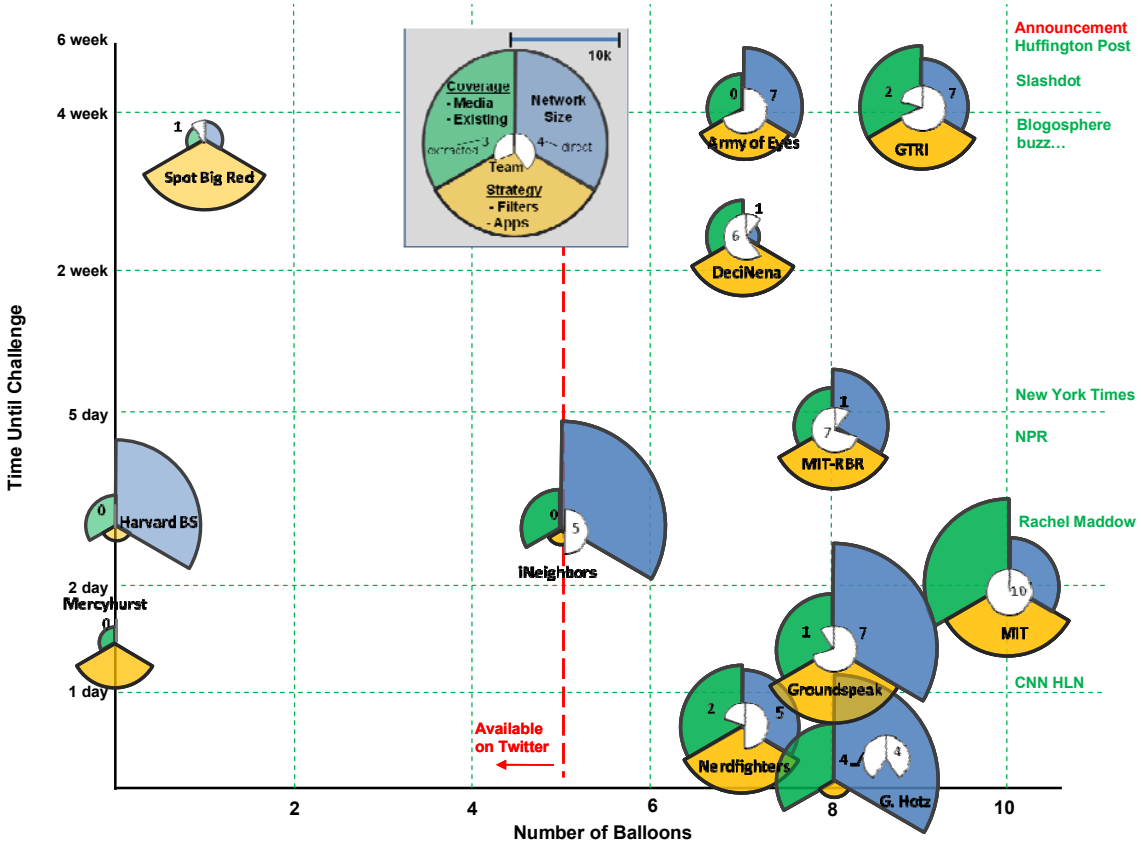


**Figure 6: DNC team performance as a function of mobilization time**

Report methods for balloon locations varied by team strategy and tool set. Observed and reported examples include secure websites, email, SMS text, phone calls to operations centers, geo-tagged photos from mobile phones, and iPhone applications that automatically reported balloons to the operations center. Some participants in the DNC, not necessarily associated with a particular team, entered or repeated a location in a Tweet. By the end of the day, five correct balloon locations were available solely from Twitter sources.

As widely anticipated, there were many false reports of balloons across the country. Some false reports were innocent reports of red balloons not associated with the DNC, but many were deliberate and systematic attempts by some teams to increase the fog and friction of the DNC for other teams. Many false reports were repeated by well-meaning but duped participants. There was even a decoy balloon launched in Royal Oaks, MI, with an impostor "DARPA official". Teams employed various strategies for filtering false reports including IP address comparison to report location, photo analysis, deployment of trusted members for confirmation, reverse white page searches and phone calls, and participant report follow-up.

### 3.1 MIT Media Lab

The MIT Media Lab team (http://balloon.mit.edu/) was the winning team, correctly identifying the locations of all 10 balloons in 8 hrs and 52 min. The MIT Media Lab team was organized within Professor Alex "Sandy" Pentland's Human Dynamics Laboratory and was led by Dr. Riley

Crane. The team designed and launched a recursive incentive recruiting method that reached almost 5,400 individuals in approximately 36 hours. The ingenuity of the recruiting method was that the incentive to join the effort was transferred undiminished with each subsequent layer of network nodes. MIT also enjoyed name recognition and mass media coverage (CNN Headline News) on execution day that helped them become one of the preferred sources to receive balloon reports. MIT collected extensive network structure data during the Challenge and plans several scientific studies of human dynamics and social networks using data from the DNC.

### 3.2 GTRI I Spy a Red Balloon

The Georgia Tech Research Institute (GTRI) I Spy a Red Balloon (ISARB) team (http://www.ispyaredballoon.com/) was one of the earliest and best organized teams to launch a website. The team was led by GTRI research scientists Erica Briscoe and Ethan Trewhitt. The GTRI team adopted the broadcast network hierarchy and enjoyed both name recognition and mass media coverage. Their intention was to donate all winnings to the American Red Cross. A key component of the ISARB strategy was search engine rank optimization for their official team website. They sought to establish links to their website from GA Tech, GTRI, and media outlets. The media coverage the team received, *e.g.* NPR, also helped push their Google search engine ranking towards the top of the search result list. The GTRI researchers expect to perform follow-on research of Challenge network data.

### 3.3 George Hotz

George Hotz learned about the Challenge the day before the balloon launch. He announced his personal effort and website (http://dudeitsaballoon.com/) in a Tweet an hour before the start of the DNC. Hotz has an existing Twitter network of almost 50,000 followers, due in no small part to his fame as a hacker (including the first untethering of the iPhone when he was 17 years old). With only an hour of preparation before the Challenge, Hotz was able to locate 8 balloons (4 from direct reports of his existing Twitter network, 4 through trades with other teams).

### 3.4 Groundspeak Geocachers

The Groundspeak team (http://www.10balloonies.com/) mobilized their extensive, pre-existing network of active geocachers using email alerts one and two days prior to balloon launch. Groundspeak is the largest geocache coordinator with an estimated active network of premium users in the hundreds of thousands (plus several hundred thousand additional free content members). Groundspeak was able to use their member database to do very effective geographic targeting of reported balloon locations for verification. In the post-Challenge interview, the president of Groundspeak emphasized that their biggest lesson learned "is that geocachers are an asset for good. We need to find better ways to mobilize our community for fun projects like this, but also for good deeds. Like Reverse 911, we should have an opt-in system for geocachers who want to be notified of these games, of emergencies, or both."

### 3.5 MIT Red Balloon Race

Two recent MIT graduates started the Red Balloon Race team (http://www.redballoonrace.com/) in the final week before the Challenge. They pursued a recruitment strategy using Facebook (their Facebook page included instructions and java script for inviting all of a user's Facebook friends to the team) and proposed a payout reward scheme that awarded prize money for balloon reports, balloon confirmations, and for referring successful balloon spotters. The Red Balloon Race team also enjoyed the brand name recognition of being associated with MIT, however they did not receive the widespread media coverage of the other MIT team.

### 3.6 Nerdfighters

The Nerdfighters mobilized an extensive, pre-existing network of regular followers of the Brotherhood 2.0 vlog. They launch a video that went viral one day before the launch and energized a very technically savvy, young group of 2,000 active balloon seekers. An additional 3,000 Nerdfighters also participated by scanning for other traffic and launching a misinformation campaign. In less than 24 hours, the Nerdfighters compiled a trusted cell phone and address list that exceeded 2,000 names that allowed them to do targeted text message dispatching for balloon verification. The overall effort was coordinated from a virtual operations center of ten individuals using Skype.

### 3.7 DeciNena

Team DeciNena (http://decinena.com/) employed a marketing recruitment strategy. Team leaders posted links to the team website in the comments section of every DNC blog they could locate, but the team never received national media attention.

### 3.8 Army of Eyes

The Army of Eyes team (http://www.armyofeyes.com/) was formed around an iPhone application that was developed by Mutual Mobile, a consortium of smart phone developers located in Austin, Texas. Application development was started soon after the initial announcement of the Challenge which allowed sufficient time for the Army of Eyes Application to be approved and offered on the iPhone AppStore.

### 3.9 iNeighbors

The iNeighbors team (http://www.i-neighbors.org/redballoon.php) was built around an existing social network designed for neighborhood watch and community organization. The team did not attempt to market or recruit members, and they did not engage in location trading. The team's objective was to see how effective the existing network of neighborhood users would be in reporting an observed event in their neighborhoods. The iNeighbors team successfully reported half of the balloons.

### 3.10 Spot Big Red

The Spot Big Red team (http://www.spotbigred.com/site/) launched their website shortly after the initial announcement of the DNC. They released a series of short videos with a contagious pitch song, had a promising payout proposal for reports and confirmations, an easily remembered url, and offered an iPhone App (though development and availability in the iPhone AppStore were delayed). The team also purchased the search word "challenge" from Google which yielded a click-through advertisement link to the Spot Big Red website. With the exception of planning for an operations center, the Spot Big Red team had a fairly well-designed strategy, but the team received no external media coverage and failed to sign-up a large number of team members. Thus despite being well-designed, the team's marketing was ineffective. The team also failed to plan for internet search and filtering during execution and only reported a single balloon.

### 3.11 Harvard Business School

A graduate of the Harvard Business School (HBS) sought to tap into the extensive network of HBS graduates. In the post-Challenge interview, the team leader claimed almost 2 million "impressions", counting HBS alumni email distribution, Tweets and alumni reTweets, and an ABCNews.com story that featured the HBS team. Despite the potentially large existing network of HBS alumni, the name recognition, and the media coverage, the team failed to report a single balloon. The team leader admits to spending too much effort on marketing and insufficient consideration of execution.

### 3.12 Mercyhurst

The Mercyhurst team consisted of students from Mercyhurst College's Department of Intelligence Studies. The team (http://sourcesandmethods.blogspot.com/2009/12/lessons-learned-darpa-balloon-challenge.html) first learned about the Challenge only two days prior to balloon launch which permitted them just 24 hours to prepare and mobilize. The Mercyhurst strategy was distinct and interesting in that they approached it from an intelligence analyst's perspective and attempted to predict where balloons might be located based on the Intelligence Preparation of the Battlefield they constructed. They also sought to identify pre-existing networks, *e.g.* law enforcement and interstate truckers, who might be in a position to see and report the balloons; however, they cite insufficient time to execute their mobilization strategy.

## 4 OBSERVATIONS AND ANALYSIS

Social networks emerged or mobilized very quickly to solve a very challenging geo-location problem. A significant number of the top finishers launched their team mobilization efforts with only a one or two day notice. The winning MIT team constructed a motivated network exceeding 5,000 individuals from just four initial nodes in less than two days. Teams built

around existing networks were able to mobilize their networks in less than a day. In one case, a highly connected individual successfully mobilized his contacts through Twitter in less than an hour. Equally impressive, a lot of teams were able to do precise, targeted dispatching to verify balloon tips. The balloon verification from initial report to confirmation by a targeted dispatch was typically less than 2 hours. As is clearly evident in Figure 6, time to mobilize was not a significant factor in relative performance.

Diffusion of the DARPA Network Challenge eventually proceeded virally, but the inflection was not until the final days before the balloon launch and it followed the extensive media coverage of the final week. A refined estimate of the diffusion proportion of mass media and social networks should follow Stanford's Dr. Jure Leskovec's ongoing analysis with MemeTracker. Nevertheless, the observations from website traffic and the efforts of the majority of the teams is that mass media was more predictable than viral transmission for the diffusion of the DNC.

It is also likely that the media coverage enjoyed by the MIT Media Lab team and the GTRI team were a significant component of the overall success of both teams. Both teams were well-organized and executed well-designed strategies, but there is little clear decisive advantage in the strategy and execution of either of these two leading teams over the rest of the field. What the MIT Media Lab team and GTRI team did possess over the other teams in the Challenge was far greater media exposure.

As previously observed during rapidly changing world events, *e.g.* the protests following the 2009 presidential elections in Iran, Twitter is an extremely fast and responsive data source. With an Internet-based SMS text relay service like Twitter, the potential coverage of a human-based sensor network is equivalent to the extent of the local cell-phone coverage. In the DARPA Network Challenge, the Tweet stream was noisy. Although it is conducive to filtering, there is a clearly recognized need for better search methods and algorithms. Although not publically available during the Challenge, Google has subsequently released a Twitter feed search option. A beta version of the search engine was tested during the DNC by a team of Google employees. It is uncertain how an improved real-time search capability would have changed the DARPA Network Challenge. What is clear is that as they existed on the day of the Challenge, Google and Bing failed to provide any real-time sense of the social space.

The Facebook friends structure proved a useful recruiting method for several teams, though it was not a decisive factor since it was readily available to all participants. In the days leading up to the Challenge, the referring volume from Facebook to the DNC website was greater than it was from any other search engine, including Google (media sources, *e.g.* the *New York Times* were greater still according to the web analytics).

The DARPA Network Challenge was a clear demonstration of the efficacy of crowd-sourcing. Not only did the Challenge demonstrate the effectiveness of event detection using distributed human sensors, but multiple geo-location strategies were identified by various teams. Initial brainstorming at DARPA identified three possible geo-location strategies; the Challenge revealed an additional five promising strategies for network geo-location. Additionally, many

well-thought blogs were written that highlight many possible applications of social network mobilization.

A final lesson from the DARPA Network Challenge is how simple and straightforward it is to rapidly assemble high fidelity location and situational awareness from willing social networks. Since traditional intelligence sources are often beyond the capability of some of our current asymmetric threats, social networks represent an obvious potential attraction for similar approaches to intelligence collection for these threats. Indeed, a social networks' intelligence source is not only attractive to our adversaries, it may be politically "off-limits" as a designed source for US intelligence due to privacy concerns. Even with complete transparency and an open-source approach, there could likely be pervasive sensitivities to government engagement with social networks. The winning MIT team made a similar conjecture that their recursive recruiting approach would probably only be effective if participants in the recruitment tree are perceived as endorsing something moral and good by their participation. Any doubt or distrust of the purpose of a designed network will increase the reluctance of individuals to join and recruit their friends. The potential use of social networks by adversaries for gathering domestic intelligence as well as trusted use by our government for the common good deserves further consideration.

## 5 RECOMMENDATIONS

The DARPA Network Challenge as a diffusion experiment generated data (blogs, mainstream news media, and Twitter data) that were collected by Dr. Carlos Guestrin (Carnegie Mellon University) and Dr. Jure Leskovec (Stanford). This data should provide a quantified comparison of the effectiveness of different distribution and mobilization efforts. Additionally, a high-fidelity comparison of the relative proportions and source flow between mass media and social media is possible with Dr. Leskovec's MemeTracker methods. The MIT and GTRI teams are also planning scientific network analysis of data they collected during the Challenge. These studies and others that may be planned should be encouraged and reviewed.

The Challenge revealed how fast and dynamic Twitter can be as a responsive data source, but it also confirmed the inherent noise in Tweet data streams as well as how difficult it is to extract the desired information. Both Google and Microsoft claim to be developing tools that permit real-time search of Twitter feeds. Further study and review of these efforts and products is warranted.

Subsequent experiments that correspond more closely with actual intelligence objectives should also be pursued. Members of the Intelligence Science Board were interested in experiments designed to study more realistic intelligence scenarios. Possible variations to the Network Challenge are:

1) Execute a balloon geo-location experiment in another country, *e.g.* Turkey, but restrict the team leaders to those in a geographic different region, *e.g.* the U.S., Europe, and

India. This might reveal how foreign interests can motivate, recruit, and mobilize people from other cultures, language, and religions. Another interesting observation would be how observer networks in the balloon country organize and mobilize and how they interact with each other and the foreign participants.

2) Execute an experiment where a team commits an observable act from a list of possible actions. For example, the team can launch a balloon of an unknown color at an unknown location, but the color and location are part of a finite set of choices. A second team must determine the action of the first team using a crowd-sourced sensor network. The effective organization and mobilization methods for social networks by the second team are the data of interest.

3) Execute a targeted message mobilization experiment. For example, teams have to use social networks to deliver a message to a particular target at an unknown geographic location, receive a response, and transmit the response from the target back to the origin of the first message.

4) Execute an experiment similar to the DNC but with no financial reward. This should help reveal the relative merits of prize vs. pride in recruiting, motivation, and mobilization.

## 6 CONCLUSIONS

The power of social networks and the manner in which they are poised to transform our society have clearly been recognized. There are many examples of emergent, coordinated behavior in social networks, *e.g.* in the contributions to Wikipedia or North Korea Uncovered, as well as social networks being used as tools to organize large groups of people with common interests, *e.g.* in the 2008 US presidential campaigns and in the protests following the 2009 Iranian presidential election. The DARPA Network Challenge revealed several promising means for using social networks to mobilize groups of people for a specific purpose. The DARPA Network Challenge also demonstrated the speed in which social networks could potentially be used to solve challenging, national geo-location and intelligence problems.

The network mobilization in the DNC was far faster than expected. We can easily conclude that the mobilization time required for a specific purpose is on the order of days instead of weeks. Mobilization efforts based on mass media are more reliable and effective than diffusion through social media. Although there are examples of pure viral transmission of information through social channels, the results are unpredictable. Additionally, viral events are often picked-up and reported by traditional media, blurring the distinction of the viral transmission channel. The DNC witnessed examples of mobilization attempts that were initially informed by mass media, but that were subsequently spread by team viral efforts. Nevertheless, the ultimate conclusion from the DNC is that with sufficient diffusion and penetration, either through mass media or social media, the mobilization of a social network can proceed rapidly.

The mobilization success for social networks is likely to be dependant on the nature of the task. Based on the post-Challenge interviews, the success of social networks in locating and reporting balloons during the DARPA Network Challenge may have stemmed as much from the fun, game-like aspect of the Challenge as from the financial incentive of the prize money. Fortunately, successful recruitment and mobilization efforts are possible when the purpose of the mobilization rests merely upon altruistic motives or are perceived as benefiting the common good. It is not known if financial greed is sufficient to motivate a viral recruitment method in networks if the task serves an ill-purpose, but we can hope that it would experience significant transmission friction. The potential use of social networks by adversaries for gathering domestic intelligence as well as trusted use by our government for the common good deserves further consideration.

## Appendix 1

## DARPA Network Challenge Final Standings

| Place | Name | Hometown | # Balloons | Date/Time |
|---|---|---|---|---|
| 1 | MIT Red Balloon Challenge Team | Cambridge, MA | 10 | 6:52:41 PM |
| 2 | GTRI "I Spy a Red Balloon" Team | Atlanta, GA | 9 | 6:59:11 PM |
| 3 | Chris Rodriguez and Tara Chang | Cambridge, MA | 8 | 6:52:54 PM |
| 4 | Dude It's a Balloon | Glen Rock, NJ | 8 | 7:42:41 PM |
| 5 | Groundspeak Geocachers | Seattle, WA | 7 | 4:02:23 PM |
| 6 | Army of Eyes - Mutual Mobile, Inc. | Austin, TX | 7 | 4:33:20 PM |
| 7 | Team DeciNena | Evergreen, CO | 7 | 6:46:37 PM |
| 8 | Anonymous | Anonymous | 7 | 7:16:51 PM |
| 9 | Nerdfighters | Missoula, MT | 7 | 8:19:24 PM |
| 10 | iSchools DARPA Challenge Team | State College, PA | 6 | 6:13:08 PM |
| 11 | i-Neighbors.org Red Balloon Team | Philadelphia, PA | 6 | 7:18:00 PM |
| 12 | Team 40K for LAF | West Chester, PA | 6 | 7:22:23 PM |
| 13 | Jon Cannell's Red Balloon Challengers | Port Charlotte, FL | 5 | 4:19:06 PM |
| 14 | Google & Friends | New York, NY | 5 | 5:01:40 PM |
| 15 | Anonymous | Anonymous | 5 | 5:28:18 PM |
| 16 | Fark.com | | 5 | 5:35:56 PM |
| 17 | 10RedBalloons.com Team | Charlottesville, VA | 5 | 7:24:29 PM |
| 18 | Team AR15.com | | 5 | 7:24:51 PM |
| 19 | Anonymous | | 5 | 8:25:10 PM |
| 20 | Anonymous | | 4 | 3:59:24 PM |
| 21 | Anonymous | | 4 | 4:23:39 PM |
| 22 | Red40K.com | Provo, UT | 4 | 4:40:25 PM |
| 23 | Anonymous | | 4 | 5:01:42 PM |
| 24 | Society for Conservation GIS | | 4 | 6:46:15 PM |
| 25 | Poor College Kid | San Antonio, TX | 4 | 7:02:05 PM |
| 26 | Metafilter Team | | 4 | 7:17:00 PM |
| 27 | Anonymous | | 4 | 7:56:28 PM |
| 28 | BG | | 4 | 8:10:25 PM |
| 29 | Anonymous | | 3 | 2:58:31 PM |
| 30 | Anonymous | | 3 | 3:57:41 PM |
| 31 | Anonymous | | 3 | 4:09:43 PM |
| 32 | Anonymous | | 3 | 4:10:18 PM |
| 33 | Santa's Red Balloons | Champaign, IL | 3 | 5:07:13 PM |
| 34 | Anonymous | | 3 | 5:15:39 PM |
| 35 | The Seen Any Red Balloons Today Team | Jackson, NJ | 3 | 6:13:15 PM |
| 36 | Anonymous | | 3 | 6:19:16 PM |
| 37 | Pinto Ridge Stable Team | New Alexandria, PA | 3 | 6:20:18 PM |
| 38 | Anonymous | | 3 | 7:03:45 PM |
| 39 | Anonymous | | 3 | 7:58:37 PM |
| 40 | IIIT-H Balloon Team | | 3 | 7:58:46 PM |
| 41 | Anonymous | | 3 | 8:21:24 PM |
| 42 | Shaun Kerrick | | 3 | 8:22:39 PM |
| 43 | Anonymous | | 2 | 2:35:32 PM |
| 44 | Edward Kim | | 2 | 2:57:56 PM |
| 45 | Anonymous | | 2 | 3:34:34 PM |
| 46 | Anonymous | | 2 | 5:01:06 PM |
| 47 | The Facebook DARPA Network Challenge Search Group | Jackson, TN | 2 | 5:06:43 PM |
| 48 | Anonymous | | 2 | 6:03:15 PM |
| 49 | Krewe of Rubes | | 2 | 6:20:49 PM |
| 50 | AJ from Ohio | | 2 | 6:22:33 PM |
| 51 | Anonymous | | 2 | 6:35:22 PM |
| 52 | Anonymous | | 2 | 6:57:05 PM |
| 53 | Kelly Maddem | Waukesha, WI | 2 | 6:59:13 PM |
| 54 | Anonymous | | 2 | 7:20:32 PM |
| 55 | Anonymous | | 2 | 7:25:38 PM |
| 56 | Anonymous | | 2 | 7:29:13 PM |
| 57 | Anonymous | | 2 | 7:44:13 PM |
| 58 | Team Vanish | | 2 | 8:00:52 PM |