# Armando L. Caro, Ph.D.

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## Experience

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| **BBN Technologies** | **Cambridge, MA** |
| Scientist | **9/2005 - 2/2010** |
| Senior Scientist | **2/2010 - Present** |

### DARPA Searchlight                    6/2019 - present

I am the Principal Investigator for the DQM project, which is sponsored by DARPA under the Searchlight program. Searchlight's obejctive is to enable an enterprise's high-priority Internet traffic to achieve its Quality of Service needs at the granularity of individual flows. BBN is developing flow-level techniques that dynamically redistribute bandwidth from low-priority traffic to high-priority traffic, without negatively affecting non-enterprise Internet traffic. Key challenges include operating with incomplete and inaccurate network analytics, managing traffic using only available network assets, and actuating traffic at opportunistic locations.

### DARPA Transparent Computing (TC)           6/2015 - 6/2019

I was the deputy Principal Investigator and a key contributor for the STARC project, which was sponsored by DARPA under the TC program. Advanced Persistent Threats (APTs) leverage the opaqueness of modern computing systems to remain undetected for extended periods of time, while acting slowly and deliberately to expand their presence in an enterprise network and achieve their goals: information exfiltration and denial of capability. The TC program aimed to improve system transparency by providing high-fidelity visibility into component interactions during system operation across all layers of software abstraction, while imposing minimal performance overhead.

BBN was developing STARC, a big data architecture comprising a multi-layer data collection architecture with an analysis and enforcement engine. The architecture ingests large amounts of granular provenance data from all enterprise systems, structures the data and makes it available for forensic and real-time analysis. The novelty is in applying the Lambda architectural pattern to enable prompt detection of APTs, and allow complete root cause analysis and damage assessment. I led the program-wide design of a common data model, which involved reaching compromises among 10 teams with several incompatible technological ideologies.

### DARPA CBMEN                         3/2012 - 5/2015

I was the Content Management Lead for the CASCADE project, which was sponsored by DARPA under the Content-Based Mobile Edge Networking (CBMEN) program. BBN was developing the network services and transport architectures to enable efficient, transparent distribution of content in mobile ad hoc network environments. Community detection techniques were used to automatically adapt the content replication and distribution approach based on network connectivity. The content-based networking stack was developed for Android devices.

### ONR/USMC DTN                        7/2011 - 9/2013

I was the Principal Investigator for the USMC Disruption-Tolerant Networking (DTN) program, which was sponsored by ONR. In July 2011, ONR entered into a Memorandum of Agreement (MOA) with Marine Corps System Command (MCSC) to work with BBN on advancing BBN's DTN software towards a transitionable USMC DTN system that provides effective, reliable delivery of UDP and TCP traffic in the presence of long duration link outages. BBN integrated

DTN into Cisco 2951 series routers and developed an architecture for adding DTN-enabled Cisco routers into the USMC Network on the Move (NOTM) system.

### ONR WildCard                                                5/2011 - 5/2012

I was the Principal Investigator for the WildCard program, which was sponsored by ONR. BBN was investigating predictive content delivery techniques for mitigating network bottlenecks and reducing user-perceived latencies. The goal was to strategically pre-position content in anticipation of users' needs to more effectively utilize limited bandwidth resources and mitigate intermittent connectivity.

### DARPA WNaN                                                12/2007 - 5/2011

I was the Routing Lead for the PIRANA project, which is sponsored by DARPA under the Wireless Networking after Next (WNaN) program. BBN was developing scalable, adaptive, ad hoc networks which exploit very inexpensive, yet flexible software radios. Innovative aspects of the program include the incorporation of DTN technology for disconnected operation, dynamic spectrum access for finding and exploiting any available frequencies rather than using pre-allocated frequencies, and exploitation of multichannel MIMO.

### DARPA DTN                                                12/2006 - 5/2010

I was the Principal Investigator for the SPINDLE project, which was sponsored by DARPA under the Disruption Tolerant Networking (DTN) program. BBN was developing DTN technologies that enable access to information when stable end-to-end paths do not exist and network infrastructure access cannot be assured. DTN technology leverages persistent storage at each hop and opportunistic connectivity episodes to overcome end-to-end connectivity disruptions. Phase 3 was a $9M project with approximately 25 people.

### NASA SELENE                                                2/2008 - 6/2011

I was the Principal Investigator for BBN's effort in the SELENE project, which was sponsored by NASA to develop the SELENE network for the Human Lunar Outpost. BBN was investigating a hybrid routing algorithm combining Mobile Ad Hoc Networks (MANETs) and Disruption Tolerant Networks (DTNs) for networking EVA radios in the Human Lunar Outpost.

### DARPA ACERT                                                1/2006 - 11/2006

I was the Configuration Management Lead and a key developer for the ADROIT project, which was sponsored by DARPA under the Adaptive Cognition-Enhanced Radio Teams (ACERT) program. BBN was building an open-source software-defined data radio, intended to be controlled by cognitive applications. The goal was to create a system that enables teams of radios, where each radio has its own cognitive controls and the ability to collaborate with other radios, to create cognitive radio teams that dynamically adapt in real-time to environmental conditions.

## Protocol Engineering Lab (PEL), University of Delaware                Newark, DE
## Graduate Research Assistant                                        6/1998 - 5/2005

### End-to-End Fault Tolerance Using Transport Layer Multihoming

My dissertation investigated transport layer techniques that improve end-to-end fault tolerance and throughput. Often, access links (for both clients and servers) are a single point of failure for end-to-end reachability. Routing protocols (in particular, BGP) may also take a significant amount of time (often tens of minutes) to converge on a new route when a link failure is detected. Multihoming support at the transport layer addresses both types of failures by allowing a transport

layer session to bind multiple IP addresses at each endpoint. This feature provides both endpoints with multiple paths with which to communicate, and thus the ability to failover to an alternate path when a path failure occurs.

I investigated multihoming retransmission policies and failover thresholds with the Stream Control Transmission Protocol (SCTP). A key contribution of my dissertation was a new SCTP retransmission policy that was incorporated into a revised SCTP specification (RFC 4960), which obsoletes the original specification (RFC 2960).

**Nokia Research Center** <span style="float:right">**Helsinki, Finland**</span>
**Research Intern** <span style="float:right">**Summer 2001**</span>

### SCTP Simulation Studies

I lead the development of an SCTP model for the ns-2 network simulator. I evaluated SCTP and PR-SCTP for protocol correctness and performance, and worked with the PR-SCTP authors to correct protocol errors in the specification.

**Telcordia Technologies** <span style="float:right">**Morristown, NJ**</span>
**Research Intern** <span style="float:right">**Summers 1999 & 2000**</span>

### ITSUMO QoS <span style="float:right">Summer 2000</span>

The Internet Technologies Supporting Universal Mobile Operations (ITSUMO) project was a collaboration between Telcordia Technologies and Toshiba Research formed in February 1999 to develop IP-centric access systems integrating voice, data, and multimedia services for mobile devices. I co-designed the dynamic service level agreement/specification negotiation protocol and the diffserv-based QoS architecture. I implemented a complete prototype of the architecture, and demonstrated that mobile hosts could roam freely between domains while transmitting and receiving video and voice at the negotiated QoS.

### ITSUMO Secure Registration <span style="float:right">Summer 1999</span>

I implemented a unified authentication mechanism for an open source implementation of DHCP and Mobile IP.

**Protocol Engineering Lab, University of Delaware** <span style="float:right">**Newark, DE**</span>
**Undergraduate Research Assistant** <span style="float:right">**6/1996 - 6/1998**</span>

### ReMDoR

I co-designed and co-developed an interactive Remote Multimedia Document Retrieval (ReMDoR) client-server system. The motivation for ReMDoR was to demonstrate the practical benefits of using a partially ordered and partially reliable transport service for multimedia communications. ReMDoR interfaced with our lab's Universal Transport Library (UTL) to dynamically choose among several experimental transport protocols.

## Book Chapters

1. A. Caro. Fault Tolerance. *Multihomed Communication with SCTP (Stream Control Transmission Protocol)*, CRC Press, 2012.

# Journal Publications

1. T. Strayer, S. Nelson, A. Caro, J. Khoury, B. Tedesco, O. DeRosa, C. Clark, K. Sadeghi, M. Matthews, J. Kurzer, P. Lundrigan, V. Kawadia, D. Ryder, K. Gremban, W. Phoel. Content Sharing with Mobility in an Infrastructure-less Environment. *Computer Networks*, October 2018.

2. G. Troxel, et al. Enabling Open-source Cognitively-Controlled Collaboration Among Software-Defined Radio Nodes. *Computer Networks*, March 2008.

3. A. Caro, P. Amer, R. Stewart. Retransmission Policies for Multihomed Transport Protocols. *Computer Communications*, June 2006.

4. A. Caro, P. Amer, R. Stewart. Rethinking End-to-End Failover with Transport Layer Multihoming. *Annals of Telecommunications*, 61(1-2), January-February 2006.

5. A. Caro, J. Iyengar, P. Amer, S. Ladha, G. Heinz, K. Shah. SCTP: A Proposed Standard for Robust Internet Data Transport. *IEEE Computer*, 36(11):56-63, November 2003.

6. P. Amer, S. Iren, G. Sezen, P. Conrad, M. Taube, A. Caro. Network-Conscious GIF Image Transmission over Internet. *Computer Networks*, 31(7):693-708, April 1999.

# Conference Publications

1. T. Strayer, R. Ramanathan, D. Coffin, S. Nelson, M. Atighetchi, A. Adler, S. Blais, B. Thapa, W. Tetteh, V. Shurbanov, K. Haigh, R. Hain, C. Rock, E. Do, A. Caro, D. Ellard, S. Loos, M. Beckerle, S. Lawrence. Mission-Centric Content Sharing Across Heterogeneous Networks. *International Conference on Computing, Networking and Communications (ICNC)*, February 2019.

2. J. Khoury, S. Nelson, A. Caro, V. Kawadia, D. Ryder, T. Strayer. Efficient and Expressive Access Control Architecture for Content-based Networks. *IEEE MILCOM*, October 2014.

3. T. Strayer, V. Kawadia, A. Caro, S. Nelson, D. Ryder, C. Clark, K. Sadeghi, B. Tedesco, O. DeRosa. CASCADE: Content Access System for the Combat- Agile Distributed Environment. *IEEE MILCOM*, November 2013.

4. G. Troxel, et al. Cognitive Adaptation for Teams in ADROIT. *IEEE GLOBECOM*, November 2007.

5. R. Krishnan, et al. The SPINDLE Disruption-Tolerant Networking System. *IEEE MILCOM*, October 2007.

6. G. Troxel, et al. Adaptive Dynamic Radio Open-source Intelligent Team (ADROIT): Cognitively-controlled Collaboration among SDR Nodes. *First IEEE Workshop on Networking Technologies for Software Defined Radio (SDR) Networks*, Reston, VA, September 2006, Invited.

7. A. Caro, P. Amer, R. Stewart. Retransmission Schemes for End-to-End Failover with Transport Layer Multihoming. *IEEE GLOBECOM*, Dallas, TX, November 2004.

8. S. Ladha, P. Amer, A. Caro, J. Iyengar. On the Prevalence and Evaluation of Recent TCP Enhancements. *IEEE GLOBECOM*, Dallas, TX, November 2004.

9. A. Caro, P. Amer, R. Stewart. End-to-End Failover Thresholds for Transport Layer Multihoming. *IEEE MILCOM*, Monterey, CA, November 2004.

10. A. Caro, P. Amer, R. Stewart. Transport Layer Multihoming for Fault Tolerance in FCS Networks. *IEEE MILCOM*, Boston, MA, October 2003.

11. S. Ladha, P. Amer, A. Caro. On The Evaluation of Transport Protocols for FCS Networks. *IEEE MILCOM*, Boston, MA, October 2003.

12. A. Caro, P. Amer, J. Iyengar, R. Stewart. Retransmission Policies with Transport Layer Multihoming. *IEEE International Conference on Networking (ICON)*, Sydney, Australia, September 2003.

13. J. Iyengar, A. Caro, P. Amer, G. Heinz, R. Stewart. Making SCTP More Robust to Changeover. *International Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS)*, Montreal, Canada, July 2003.

14. P. Conrad, A. Caro, P. Amer. ReMDoR: Remote Multimedia Document Retrieval over Partial Order Transport. *ACM Multimedia*, Ottawa, Canada, September 2001.

15. P. Conrad, G. Heinz, A. Caro, P. Amer, J. Fiore. SCTP in Battlefield Networks. *IEEE MILCOM*, Washington, DC, October 2001.

16. J.C. Chen, A. Caro, A. McAuley, S. Baba, Y. Ohba, P. Ramanathan. A QoS Architecture for Future Wireless IP Networks. *IASTED International Conference on Parallel and Distributed Computing and Systems (PDCS) 2000*, Las Vegas, NV, November 2000.

17. S. Iren, P. Amer, A. Caro, P. Conrad, G. Sezen, M. Taube. Network- Conscious Compressed Image Transmission over Battlefield Networks. *IEEE MILCOM*, Boston, October 1998.

18. P. Conrad, P. Amer, M. Taube, G. Sezen, S. Iren, A. Caro. Testing Environment for Innovative Transport Protocols. *IEEE MILCOM*, Boston, October 1998.

19. P. Amer, S. Iren, G. Sezen, P. Conrad, M. Taube, A. Caro. Network-Conscious GIF Image Transmission over Internet. *International Workshop on High Performance Protocol Architectures (HIPPARCH)*, London, June 1998.

20. P. Conrad, P. Amer, E. Golden, S. Iren, R. Marasli, A. Caro. Transport QoS over Unreliable Networks: No Guarantees, No Free Lunch! *IFIP International Workshop on Quality of Service (IWQOS)*, New York, NY, May 1997.

## Patents

1. T. Strayer, J. Khoury, A. Caro, V. Kawadia, S. Nelson. Policy-based Access Control in Content Networks. Raytheon BBN Technologies Corp, 2017. Patent No. US 9,571,463 B2.

## IETF RFCs

1. Y. Nishida, P. Natarajan, A. Caro, P. Amer, K. Nielsen. SCTP-PF: A Quick Failover Algorithm for the Stream Control Transmission Protocol. RFC 7829, April 2016.

2. R. Stewart, I. Arias-Rodriguez, K. Poon, A. Caro, M. Tuexen. Stream Control Transmission Protocol (SCTP) Specification Errata and Issues. RFC 4460, April 2006.

## Education

**Ph.D. in Computer and Information Sciences**                    **August 2005**
University of Delaware
**Advisor:** Prof. Paul D. Amer
**Dissertation:** *End-to-End Fault Tolerance Using Transport Layer Multihoming*

**M.S. in Computer and Information Sciences**                    **May 2000**
University of Delaware

**B.S. with Distinction in Computer and Information Sciences**                    **May 1998**
University of Delaware
**Thesis:** *ReMDoR 2.0: Remote Multimedia Document Retrieval Over Partially-Ordered, Partially-Reliable Transport Protocols*

## Technical Expertise

Content-Based Networks, Disruption-Tolerant Networks, Wireless and Mobile Ad Hoc Networks, Transport Protocols

## Development

Golang, Python, Java, C/C++, Android, Linux