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University of Southern California
Contracts & Grants
3720 S. Flower St.
Los Angeles, CA 90089 -0701

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UU	UU	UU	UU		Amir Avestimehr
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as of 18-Mar-2022

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INVESTIGATOR(S):

Name: Amir Salman Avestimehr
Email: avestime@usc.edu
Phone Number: +12137407326
Principal: Y

Organization: **University of Southern California**
Address: Contracts & Grants, Los Angeles, CA 900890701
Country: USA
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Report Date: 30-Mar-2022
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Final Report for Period Beginning 28-Sep-2018 and Ending 30-Dec-2021

Title: Network Sciences: Coded Computing: A Transformative Framework for Tactical Wireless Edge Computing

Begin Performance Period: 28-Sep-2018
End Performance Period: 30-Dec-2021
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Submitted By: Amir Avestimehr
Email: avestime@usc.edu
Phone: (+12) 137-407326

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STEM Degrees:

STEM Participants:

Major Goals: Our goal in this project is to develop a foundation for the design of coded computing in order to tackle the key bottlenecks that arise in tactical wireless edge computing, namely resource (in particular bandwidth) constraints and high dynamics due to mobility and disruptions in service. In particular, our proposed research plan consists of the following main thrusts. Thrust 1: Minimum Bandwidth Coded Computing (MBCC). In this thrust we focus on the bandwidth bottleneck of large-scale tactical edge computing, and develop coded computing strategies that effectively inject computation redundancy to minimize the communication load. Thrust 2: Maximum Robustness Coded Computing (MRCC). In this thrust we consider the resiliency of tactical edge computing to network dynamics, and generalize our framework to ac- count for failing, straggling, and overloaded nodes in the network. Thrust 3: Practical Demonstrations. In parallel to the first two research thrusts, we will also design experiments that can primarily be used to test out the theory and develop optimal and near optimal resource allocation algorithms for efficient distributed edge computing.

Accomplishments: (1) Minimum Bandwidth Coded Computing

(a) Coded Private ML: A Scalable Approach for Privacy-Preserving Collaborative Machine Learning. We have considered a collaborative learning scenario in which multiple data-owners wish to jointly train a logistic regression model, while keeping their individual datasets private from the other parties. We have proposed CodedPrivateML, a fully-decentralized training framework that achieves scalability and privacy-protection simultaneously. Our protocol provides strong statistical privacy guarantees against colluding parties (adversaries) with unbounded computational power, while achieving up to 16X speedup in the training time against the benchmark protocols. This work was published in NeurIPS 2019.

(b) TACC: Topology-Aware Coded Computing for Distributed Graph Processing. This article proposes a coded distributed graph processing framework to alleviate the communication bottleneck in large-scale distributed graph processing. In particular, we propose a topology-aware coded computing (TACC) algorithm that has two novel salient features: (i) a topology-aware graph allocation strategy, and (ii) a coded aggregation scheme that combines the intermediate computations for graph processing while constructing coded messages. This work was published in IEEE Transactions on Signal and Information Processing over Networks.

(c) Turbo-Aggregate: Breaking the Quadratic Aggregation Barrier in Secure Federated Learning. Federated learning is gaining significant interests as it enables model training over a large volume of data that is distributedly stored over many users, while protecting the privacy of the individual users. However, a major bottleneck in scaling federated learning to a large number of users is the overhead of secure model aggregation across many users. In fact, the overhead of state-of-the-art protocols for secure model aggregation grows quadratically with the number of users. We propose a new scheme, named Turbo-Aggregate, that in a network with N users achieves a linear secure aggregation overhead, while tolerating up to a user dropout rate of 50%. This work is published in IEEE Journal on Selected Areas in Information Theory.

(d) "CodedReduce: A fast and robust framework for gradient aggregation in distributed learning". We focus on the commonly used synchronous Gradient Descent paradigm for large-scale distributed learning, for which there has been a growing interest to develop efficient and robust gradient aggregation strategies that overcome two key system bottlenecks: communication bandwidth and stragglers' delays. We proposed a joint communication topology design and data set allocation strategy, named CodedReduce (CR). We showed that CodedReduce achieves speedups of up to 27.2X and 7.0X , respectively over the benchmarks . This work is now published in IEEE/ACM Transactions on Networking.

(2) Maximum Robustness Coded Computing

(a) Lagrange Coded Computing (LCC): We have developed Lagrange Coded Computing (LCC) that significantly expands the set of computations for which coded computing can be applied to. This work was presented/published in AISTATS 2019.

(b) Timely-Throughput Optimal Coded Computing: In tactical edge computing platforms we face a critical bottleneck of unpredictability, unreliability, and high variability of computing resources. Meanwhile, there is significantly increasing demand for timely and event-driven services with deadline constraints. We developed of a dynamic computation strategy called Lagrange Estimate-and Allocate (LEA) strategy, which achieves the optimal timely computation throughput. This work was published in ACM Mobihic 2019, and was a finalist for best paper award.

(c) Speed-Adaptive Coded Computing: We have developed a dynamic workload distribution strategy for coded computation called Slack Squeeze Coded Computation (S2C2). This work was published in Proc. of 2019 Supercomputing Conference, and is a finalist of both best paper and best student paper award.

(d) "Analog Lagrange Coded Computing." We built on our strong work from last year on Lagrange Coded Computing, and extended it to the analog domain. This work was published in IEEE Journal on Selected Areas in Information Theory.

(e) "ApproxIFER: A Model-Agnostic Approach to Resilient and Robust Prediction Serving Systems". Due to the surge of cloud-assisted AI services, the problem of designing resilient prediction serving systems that can effectively cope with stragglers/failures and minimize response delays has attracted much interest. The common approach for tackling this problem is replication which assigns the same prediction task to multiple workers. This approach, however, is very inefficient and incurs significant resource overheads. Hence, a learning-based approach known as parity model (ParM) has been recently proposed which learns models that can generate parities for a group of predictions in order to reconstruct the predictions of the slow/failed workers. While this learning-based approach is more resource-efficient than replication, it is tailored to the specific model hosted by the cloud and is particularly suitable for a small number of queries (typically less than four) and tolerating very few (mostly one) number of stragglers. Moreover, ParM does not handle Byzantine adversarial workers. We propose a different approach, named Approximate Coded Inference (ApproxIFER), that does not require training of any parity models, hence it is agnostic to the model hosted by the cloud and can be readily applied to different data domains and model architectures. Compared with earlier works, ApproxIFER can handle a general number of stragglers and scales significantly better with the number of queries. Furthermore, ApproxIFER is robust against Byzantine workers. Our extensive experiments on a large number of datasets and model architectures also show significant accuracy improvement by up to 58% over the parity model approaches. This work is accepted for presentation in AAAI'2022 (a premier conference in machine learning with acceptance rate of 15%).

Training Opportunities: There were 4 phd students and 2 postdoc working on this project. This provided an excellent opportunity for training junior phd student, as well as the postdoc for mentoring students. PI Avestimehr is also a recipient of the 2020 USC Mentoring Award.

Results Dissemination: (1) Publications at top conference venues in machine learning and information theory:
- NeurIPS conference
- AAAI conference
- AISTATS Conference
- ICML Conference
- MobiHoc Conference
- ISIT Conference

(2) Publications at top journals in information theory, communications, networking, and signal processing

- IEEE Journal on Selected Areas in Information Theory
- IEEE/ACM Transactions on Networking. Published
- IEEE Transactions on Signal Processing over Networks

(3) publication of a monograph on "Coded Computing" at Now Foundations and Trends in Information Theory.

(4) many keynote talks and presentations by PI Avestimehr and his students.

Honors and Awards: (1) PI Avestimehr has received the 2019 IEEE James L. Massey Research & Teaching Award from IEEE Information Theory Society. This award is the highest honor given by the IEEE Information Theory Society to researchers under 40 years of age, and is given annually to a single recipient.
(2) PI Avestimehr was elected as an IEEE Fellow for contributions to the analysis of communication and computation over wireless networks.
(3) Best Paper Award finalist at IEEE/ACM Mobihoc 2019 (top 6 papers – the conference itself has acceptance rate of 23%)
(4) Both Best Paper Award and Best Student Paper Award finalists at IEEE/ACM High Performance Computing, Networking, Storage, and Analysis (SC19) for paper (top 4 papers)
(5) Baidu Best Paper Award at NeurIPS -SpicyFL 2020 Workshop on Scalability, Privacy, and Security in Federated Learning.
(6) PI Avestimehr was an Invited Speaker at the 2021 National Academy of Engineering (NAE) EU-US Frontiers of Engineering Symposium on the topic of privacy-preserving edge learning.
(7) PI Avestimehr and two of PhD students working on the project received a 2021 Qualcomm Innovation Award for on-device federated learning.
(8) PI Avestimehr was a recipient of 2021 “USC Mentoring Award”.
(9) PI Avestimehr is named as inaugural director of the USC-Amazon Center on Secure and Trusted Machine Learning (https://trustedai.usc.edu)

Protocol Activity Status:

Technology Transfer: Filed a patent on Lagrange Coded Computing.

PARTICIPANTS:

Participant Type: Graduate Student (research assistant)
Participant: Qian Yu
Person Months Worked: 8.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Chien-Shen Yang
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Saurav Prakash
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Jinhyun So
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)
Participant: Basak Guler
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)
Participant: Ramy Ali
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
National Academy Member: N

ARTICLES:

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Volume: Issue: First Page #:
Date Submitted: 10/7/20 12:00AM Date Published:
Publication Location:
Article Title: Coded computing for distributed graph analytics
Authors: S. Prakash, R. Pedarsani, and S. Avestimehr
Keywords: Coded computing, distributed graph analytics
Abstract: There is a growing interest in development of in-network dispersed computing paradigms that leverage the computing capabilities of heterogeneous resources dispersed across the network for processing massive amount of data is collected at the edge of the network. We consider the problem of task scheduling for such networks, in a dynamic setting in which arriving computation jobs are modeled as chains, with nodes representing tasks, and edges representing precedence constraints among tasks. In our proposed model, motivated by significant communication costs in dispersed computing environments, the communication times are taken into account. More specifically, we consider a network where servers are capable of serving all task types, and sending the results of processed tasks from one server to another server results in some communication delay that makes the design of optimal scheduling policy significantly more challenging than classical queueing networks. As the main contributions of
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Article Title: TACC: Topology-Aware Coded Computing for Distributed Graph Processing
Authors: Basak Guler, A. Salman Avestimehr, Antonio Ortega
Keywords: Coded Computing; Graph Analytics
Abstract: There is a growing interest in development of in-network dispersed computing paradigms that leverage the computing capabilities of heterogeneous resources dispersed across the network for processing massive amount of data is collected at the edge of the network. We consider the problem of task scheduling for such networks, in a dynamic setting in which arriving computation jobs are modeled as chains, with nodes representing tasks, and edges representing precedence constraints among tasks. In our proposed model, motivated by significant communication costs in dispersed computing environments, the communication times are taken into account. More specifically, we consider a network where servers are capable of serving all task types, and sending the results of processed tasks from one server to another server results in some communication delay that makes the design of optimal scheduling policy significantly more challenging than classical queueing networks. As the main contributions of
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Date Submitted: 10/7/20 12:00AM Date Published: 3/1/20 8:00AM
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Article Title: Straggler Mitigation in Distributed Matrix Multiplication: Fundamental Limits and Optimal Coding
Authors: Qian Yu, Mohammad Ali Maddah-Ali, A. Salman Avestimehr
Keywords: Coded Computing, Distributed Matrix Multiplication
Abstract: There is a growing interest in development of in-network dispersed computing paradigms that leverage the computing capabilities of heterogeneous resources dispersed across the network for processing massive amount of data is collected at the edge of the network. We consider the problem of task scheduling for such networks, in a dynamic setting in which arriving computation jobs are modeled as chains, with nodes representing tasks, and edges representing precedence constraints among tasks. In our proposed model, motivated by significant communication costs in dispersed computing environments, the communication times are taken into account. More specifically, we consider a network where servers are capable of serving all task types, and sending the results of processed tasks from one server to another server results in some communication delay that makes the design of optimal scheduling policy significantly more challenging than classical queueing networks. As the main contributions of

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Article Title: Communication-Aware Scheduling of Serial Tasks for Dispersed Computing
Authors: Chien-Sheng Yang, Ramtin Pedarsani, A. Salman Avestimehr
Keywords: Coded Computing; edge computing; dispersed computing
Abstract: There is a growing interest in development of in-network dispersed computing paradigms that leverage the computing capabilities of heterogeneous resources dispersed across the network for processing massive amount of data is collected at the edge of the network. We consider the problem of task scheduling for such networks, in a dynamic setting in which arriving computation jobs are modeled as chains, with nodes representing tasks, and edges representing precedence constraints among tasks. In our proposed model, motivated by significant communication costs in dispersed computing environments, the communication times are taken into account. More specifically, we consider a network where servers are capable of serving all task types, and sending the results of processed tasks from one server to another server results in some communication delay that makes the design of optimal scheduling policy significantly more challenging than classical queueing networks. As the main contributions of

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Article Title: CodedReduce: A Fast and Robust Framework for Gradient Aggregation in Distributed Learning
Authors: Amirhossein Reisizadeh, Saurav Prakash, Ramtin Pedarsani, Amir Salman Avestimehr
Keywords: Coded Computing, Gradient Aggregation
Abstract: A distributed computing scenario is considered, where the computational power of a set of worker nodes is used to perform a certain computation task over a dataset that is dispersed among the workers. Lagrange coded computing (LCC), proposed by Yu et al., leverages the well-known Lagrange polynomial to perform polynomial evaluation of the dataset in such a scenario in an efficient parallel fashion while keeping the privacy of data amidst possible collusion of workers. This solution relies on quantizing the data into a finite field, so that Shamir's secret sharing, as one of its main building blocks, can be employed. Such a solution, however, is not properly scalable with the size of dataset, mainly due to computation overflows. To address such a critical issue, we propose a novel extension of LCC to the analog domain, referred to as analog LCC (ALCC). All the operations in the proposed ALCC protocol are done over the infinite fields of \mathbb R/ \mathbb C but for practical implementat
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Article Title: Turbo-Aggregate: Breaking the Quadratic Aggregation Barrier in Secure Federated Learning
Authors: Jinhyun So, Basak Guler, A. Salman Avestimehr
Keywords: Federated learning, secure aggregation
Abstract: A distributed computing scenario is considered, where the computational power of a set of worker nodes is used to perform a certain computation task over a dataset that is dispersed among the workers. Lagrange coded computing (LCC), proposed by Yu et al., leverages the well-known Lagrange polynomial to perform polynomial evaluation of the dataset in such a scenario in an efficient parallel fashion while keeping the privacy of data amidst possible collusion of workers. This solution relies on quantizing the data into a finite field, so that Shamir's secret sharing, as one of its main building blocks, can be employed. Such a solution, however, is not properly scalable with the size of dataset, mainly due to computation overflows. To address such a critical issue, we propose a novel extension of LCC to the analog domain, referred to as analog LCC (ALCC). All the operations in the proposed ALCC protocol are done over the infinite fields of \mathbb R/ \mathbb C but for practical implementat
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Article Title: Analog Lagrange Coded Computing
Authors: Mahdi Soleymani, Hessam Mahdavifar, A. Salman Avestimehr
Keywords: coded computing
Abstract: A distributed computing scenario is considered, where the computational power of a set of worker nodes is used to perform a certain computation task over a dataset that is dispersed among the workers. Lagrange coded computing (LCC), proposed by Yu et al., leverages the well-known Lagrange polynomial to perform polynomial evaluation of the dataset in such a scenario in an efficient parallel fashion while keeping the privacy of data amidst possible collusion of workers. This solution relies on quantizing the data into a finite field, so that Shamir's secret sharing, as one of its main building blocks, can be employed. Such a solution, however, is not properly scalable with the size of dataset, mainly due to computation overflows. To address such a critical issue, we propose a novel extension of LCC to the analog domain, referred to as analog LCC (ALCC). All the operations in the proposed ALCC protocol are done over the infinite fields of \mathbb R/ \mathbb C but for practical implementat
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Article Title: CodedPrivateML: A Fast and Privacy-Preserving Framework for Distributed Machine Learning
Authors: Jinhyun So, Basak Guler, A. Salman Avestimehr
Keywords: coded computing, privacy preserving machine learning
Abstract: How to train a machine learning model while keeping the data private and secure? We present CodedPrivateML, a fast and scalable approach to this critical problem. CodedPrivateML keeps both the data and the model information-theoretically private, while allowing efficient parallelization of training across distributed workers. We characterize CodedPrivateML's privacy threshold and prove its convergence for logistic (and linear) regression. Furthermore, via extensive experiments on Amazon EC2, we demonstrate that CodedPrivateML provides significant speedup over cryptographic approaches based on multi-party computing (MPC).
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Authors: C. Yang, R. Pedarsani, and S. Avestimehr
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Authors: Q. Yu, S. Li, N. Raviv, M. Mousavi Kalan, M. Soltanolkotabi, S. Avestimehr,
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Authors: K Narra, Z Lin, M Kiamari, S Avestimehr, M Annavaram
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Partners

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I certify that the information in the report is complete and accurate:
Signature: Salman Avestimehr
Signature Date: 3/11/22 4:51PM

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