High-Speed Energy-Efficient DACs for 5G and beyond

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Introduction

Next generations radio base stations aim to utilize advanced high date-rate radio transceivers with large number of transmitters and antenna elements at increasingly higher carrier frequencies up to mm-wave range. Currently one of the key challenging components to enable such systems is a digital-to-analog-converter (DAC) with performance and power consumption beyond what is commercially available today.

High-speed time-interleaved ΣΔ-DAC

- First reported ΣΔ DAC with >1 GHz bandwidth and 11 GHz sampling rate.
- Highly digital and scalable solution for advanced CMOS technologies.

High-Speed Switched-Capacitor DACs

- Fastest reported SC DAC with >1 GHz bandwidth.
- Smaller capacitor mismatch and reduced voltage headroom in switches lead to higher design scalability in advanced CMOS technologies.

Research Work

Having successfully brought our research to the international front by several recent pioneering works and solutions for high-speed radio transmitter DACs with low/medium resolutions [see examples in figures to the right], in this project we aim to exploit new ideas for design of wideband DAC architectures with up to 6 GHz bandwidth, 12-14 bit resolution, more than 70 dB spurious-free dynamic range (SFDR), and a power consumption with an order of magnitude lower than today’s best solutions.

The work started with detailed survey and analysis and fundamental limits of DAC power consumption, followed by research and development of a promising low-power, high-performance DAC architecture, utilizing new solutions for compensation of process variations, device mismatches and switching distortions due to timing issues.
Real-time jamming DoS detection in safety-critical V2V C-ITS using data mining

Quentin Delooz (THI, Germany), Nikita Lyamin (HH), Denis Kleyko (LTU), Alexey Vinel (HH)

Malicious Interference in Platooning

- Vehicles exchange packets which carry information needed for automatic control of the platoon
- Attacker intentionally “kills” packets by generating harmful interference
- How to detect radio jamming in real-time?

Is radio jamming easy to implement?

- 2 μs to detect transmission + 10 μs to switch from receive to transmit = 12 μs reaction delay

Reactive Jamming Models

1. Random jamming:
   - Detect the transmission and with probability \( p \) “kill” the packet
   - Time

2. ON-OFF jamming:
   - Detect the transmission and with probability \( p \) “kill” \( K \) subsequent packets
   - Time

AI-empowered Detector: the Performance

- The detection delay is at most 2T, where \( T \) is the CAM generation period (i.e. delay is less than 200 ms for around 10Hz CAM)
- Detection capabilities are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Random Jamming</th>
<th>ON-OFF Jamming</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>( 5 ) &amp; ( 15 ) &amp; ( 20 ) &amp; ( 25 )</td>
<td>( 1.00 ) &amp; ( 0.992 ) &amp; ( 0.986 ) &amp; ( 0.983 ) &amp; ( 0.978 ) &amp; ( 0.997 ) &amp; ( 0.995 ) &amp; ( 0.993 ) &amp; ( 0.986 ) &amp; ( 0.983 ) &amp; ( 0.978 ) &amp; ( 0.997 ) &amp; ( 0.995 ) &amp; ( 0.993 ) &amp; ( 0.986 ) &amp; ( 0.983 ) &amp; ( 0.978 )</td>
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</tr>
<tr>
<td>TNR, TPR</td>
<td>0.992</td>
<td>0.997</td>
</tr>
<tr>
<td>( p )</td>
<td>0.005</td>
<td>0.05</td>
</tr>
<tr>
<td>( K )</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Future work: from the simulations to the experiments:
- Validate the concepts with real measurement data (e.g. from industrial platooning projects)
Slip-Angle Feedback Control for Autonomous Safety-Critical Maneuvers At-the-Limit of Friction[1]

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Department of Electrical Engineering, Linköping University

Abstract
From the basis of optimal control, a closed-loop controller for autonomous vehicle maneuvers at-the-limit of friction is developed. The controller exploits that the optimal solution tends to be close to the friction limit of the tires. This observation allows for simplifications that enable the use of a proportional feedback control in the control loop, which provides a smooth trajectory promising for realization in an actual control system. The controller is in comparison with an open-loop numerical optimal control solution shown to exhibit promising performance at low computational cost in a challenging turn scenario.

High-Level Control
The scenario considered is a left-hand turn with constant curvature, where the goal of the high-level control is to minimize the maximum distance to the center of the turn. Equivalent to the method in [2], the solution is approximated by the use of a friction-limited particle model.

Friction Ellipse
In [3] it was found that individual tire forces are close to the friction-ellipse limit of the tires. Assume the solution for each tire is on the friction-ellipse boundary:

\[ F_{x,i} = \mu_{i} \cdot F_{z,i} \cos(\phi) \]
\[ F_{y,i} = \mu_{i} \cdot F_{z,i} \sin(\phi) \]

Problem (P1) is then reduced to the analytically solvable problem of finding \( \phi_i \):

\[ \phi_i^* = \arg \max_{\phi} \left( \mu_{i} \cdot \cos(\phi) \cos(\theta) + \mu_{i} \cdot \sin(\phi) \sin(\theta) \right) \] (P2)

Simulations & Optimization
The developed controller is compared with open-loop numerical optimal control and the steering law used in [2].

- CL FE, developed controller.
- CL LM, steering law used in [2].
- OL NOC, numerical optimal control.

A double-track model with longitudinal and lateral load transfer is used for both simulation and optimization in the JModelica.org framework.

Control Structure

![Block diagram of the closed-loop controller.](image)

The closed-loop control strategy is based on maximizing the acceleration in a globally fixed direction in the spirit of [2]. In [3] it was observed to be close to optimal to momentarily maximize the acceleration. The problem can mathematically be stated as finding the optimal input \( u^* \):

\[ u^* = \arg \max_{u \in U} \left( F_{x,i}(u) \cos(\theta) + F_{y,i}(u) \sin(\theta) \right) \] (P1)

Results

<table>
<thead>
<tr>
<th>( v_0 ) [km/h]</th>
<th>( R_0 ) [m]</th>
<th>CL FE</th>
<th>CL LM</th>
<th>OL NOC</th>
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<tr>
<td>70</td>
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<td>90</td>
<td>1.36</td>
<td>1.36</td>
<td>1.31</td>
</tr>
</tbody>
</table>

Bibliography


Figure 1: Block diagram of the closed-loop controller.

Figure 2: Friction ellipse for a tire. The angle \( \theta_i \) indicates the direction to maximize the tire forces in. The filled circle indicates the corresponding maximum.

Figure 3: Path for the different controllers for \( v_0 = 90 \) km/h and \( R_0 = 40 \) m.

Figure 4: Steering angle for the different controllers for \( v_0 = 90 \) km/h and \( R_0 = 40 \) m.
Channel Hardening in Massive MIMO – a Measurement Based Analysis

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Introduction and motivation
One goal for future wireless communication systems is to support critical communications, meaning that high reliability is required. A promising technology to reach this is massive MIMO, where the base stations are deployed with a large number of antennas. Thereby spatial diversity can be exploited in order to increase reliability. This means that small-scale fading decreases and the channel behaves deterministically, which is called channel hardening. Here, channel hardening is analyzed based on measurements in an indoor auditorium.

Measurement scenario and equipment
We analyze channel measurements with a 128-port cylindrical array and nine closely-spaced users in an indoor auditorium. The array consists of 64 dual-polarized patch antennas and the users have omni-directional antennas with vertical polarization. User antennas are tilted 45 degrees and are randomly moved in a small area.

The definition of channel hardening used here

\[
\frac{\text{Var}(\|h_k\|^2)}{(\mathbb{E}(\|h_k\|^2))^2} \to 0, \quad \text{as } M \to \infty
\]

Standard deviation of channel gain for each base station antenna in the array
Some antennas experience larger variations.

Channel gain over frequency and time for 128 antennas vs the single strongest antenna

Channel gain over frequency and time for 128 antennas vs the single weakest antenna

Conclusions and future work
The measurements show a significant channel hardening effect in massive MIMO systems, but it is lower than theoretically expected. The result is a flatter channel in both time and frequency. Channel hardening, when increasing the number of base station antennas, is evaluated with the result that the standard deviation of channel gain decreased with 3.2-4.6 dB. The amount of channel hardening that can be expected is dependent on the base station antenna arrangement, the order in which the antennas are chosen, whether the antenna elements are in LOS or NLOS and the users’ position and interaction with the environment. Future work will include extending this analysis to further narrow down the parameters that create channel hardening in a practical scenario.
**Experiments**

**Adaptive Fusion of Model Predictions**

Deep and shallow models need to be trained independently.

Deep prediction $y_d(t)$: High robustness but poor localization.

Shallow prediction $y_s(t)$: Accurate localization but noisy.

How to optimally fuse these model predictions?

$$y(t) = \lambda_0 y_d(t) + \lambda_1 y_s(t)$$

We desire the following characteristics of the fusion:

1. Minimize ambiguity in the prediction, i.e., single mode
2. Maximize sharpness of prediction to benefit accuracy
3. Should be dynamically adaptive to changes

We propose a quality measure of a candidate location $s^*$:

$$Q_t(s) = \min_{s} \frac{y_d(t) - y_s(t)}{\Delta(t - r)}$$

This quality score promotes (1) and (2).

We optimize (1) w.r.t. $r$ and the coefficients $\beta = (\beta_0, \beta_1)$:

$$L_C(\beta) = -Q_t(s) + \mu (\beta_0^2 + \beta_1)$$

subject to:

$$\beta_0 + \beta_1 = 1, \quad \beta_0 \geq 0, \quad \beta_1 \geq 0$$

Solved as a sequence of QP problems for a set of candidate states $s^*$, by introducing a slack variable $\xi$.

---

**Baseline Tracker: Efficient Convolution Operator (ECO)**

Convolution operator:

- Predicts the continuous detection scores of the target given a feature map $x$

Tracking model:

- Early fusion of features
- Least squares regression
- Optimized in the Fourier domain

Continuous filters

Training sample (concatenation of deep and shallow features)

Desired output scores (label function)

Spatial regularization

$E(T, P) = \sum_j \sum_d \alpha_j |S_f(\tau_j) - y_d|^2 + \sum_d \|P_d\|^2$ Sample weights

Continuous filters

Desired output scores (label function)

Spatial regularization

$E(T, P) = \sum_j \sum_d \alpha_j |S_f(\tau_j) - y_d|^2 + \sum_d \|P_d\|^2$

**Experiments**

**Need for Speed**

**UAV123**

**OTB-2015**

MCPF SimDCC CSRDCF COOT MCC TTest ECO CFDCF CFWCR LSRAT Ours

EAO 0.249 0.249 0.247 0.267 0.270 0.274 0.280 0.286 0.303 0.323 0.375

Robustness 0.422 0.473 0.356 0.318 0.323 0.276 0.281 0.267 0.218 0.162

Accuracy 0.516 0.500 0.491 0.494 0.475 0.522 0.485 0.509 0.494 0.502 0.532
Motion Planning using Positively Invariant Sets

1. Introduction

Motion planning is a key component of an autonomous system, responsible for providing reference trajectories and paths that the vehicle should follow. This work deals with design and implementation of a motion-planning algorithm using positively invariant sets, based on [3] and [2]. Under mild assumptions, the algorithm uses feedback control and positively invariant sets to generate guaranteed collision-free closed-loop trajectory tracking for safe and efficient maneuvering and obstacle avoidance. We extend the theoretical justifications to time-varying velocities and more complex driving scenarios, which is further demonstrated using a small-scale robot platform. For more details, see [3].

2. Motion Planning using Positively Invariant Sets

2.1 Positively Invariant Sets

A set \( M \) is a positively invariant set (PIS) if

\[
x_0 \in M \Rightarrow \exists \tau \geq 0, \forall t \geq 0, x(t) \in M.
\]

If we at any time enter the set, we are guaranteed to never leave, see Fig. 1. This together with feedback control can be used to generate safe reference trajectories for motion planning.

Motion Planning with Constant Velocity

Under the assumption that the autonomous vehicle has a constant longitudinal velocity, the lateral dynamics can be expressed as an LTI system in a road-aligned coordinate system. The road is discretized into a grid of setpoints as illustrated in Fig. 2. For each lateral setpoint \( r \), a linear state-feedback steering controller is designed using LQR:

\[
d_k = -L(x_k - r_x) + \alpha \dot{x}_k
\]

where \( \alpha \) is the gain-constraint of the LQR. The associated lyapunov function \( V_k(s) \) implicitly defines an elliptical PIS \( \mathcal{O}_k \) around each setpoint. The size of the PIS is computed to ensure that physical input and output constraints are not violated. For each time step \( \tau \), the size of the safe region that can be reached increases, as illustrated in Fig. 3. We can hence construct a connectivity graph of the setpoints that are connected by safe trajectories. By predicting the motion of nearby obstacles, Djikstra's algorithm can then be used to compute a reference trajectory that safely avoids obstacles. The motion planner operates in a fashion similar to receding horizon control and the reference path is updated with a frequency of \( 2 \text{ Hz} \).

Motion Planning with Time-Varying Velocity

In reality, the autonomous vehicle must be able to adjust its speed in order to avoid collisions. We solve this by discretizing the operating region for the longitudinal velocity and iteratively searching for a safe reference trajectory at different constant velocity levels. For moderate accelerations, \( V_k(s) \) can be shown to be a lyapunov function also for deviated velocities in a certain interval. This interval is represented by the colored regions in Fig. 4. By employing a gain-scheduling approach and adjusting the parameters of the steering controller, we can find new lyapunov functions with associated PISs for the entire operating region. This enables us to generate safe reference trajectories also for time-varying velocities.

Acknowledgments & References

We would like to extend our gratitude to our supervisors Dr. Karl Berntorp and Dr. Bjorn Döflson, as well as our examiner Prof. Anders Robertson. Without them this work would not have been possible.


New Approaches for Improving Latency and Reliability for 5G Wireless

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1: Linköping University, Norrköping, Sweden; 2: Nokia Bell-Labs, Stuttgart, Germany; 3: University of Maryland, College Park, US

Dynamic Power Control for Packets with Deadlines

Introduction and Motivation
- In many applications, data must be transmitted by some deadline.
- Examples: Online gaming, multimedia streaming, and 5G new applications (e.g. autonomous driving).
- Adapting transmission power: elimination of transmission errors.
- Limited power of mobile devices—energy efficiency issues.

Contributions
- Online low complexity algorithm based on Lyapunov optimization theory.
- Minimization of the drop rate under power consumption constraints.
- Good trade-off between average power consumption and drop rate.

System Model
- N users transmitting over wireless fading channel.
- P_{ms}: channel in bad state. P_{gs}: channel in good state.
- Transmission power level at each time slot for each user: p_i(t). Drop indicator: D_i(t).
- Drop rate: D_i ≤ lim_{t→∞} D_i(t), ∀i ∈ N.
- Average power consumption: \overline{p}_i ≤ lim_{t→∞} \overline{p}_i(t), ∀i ∈ N.

Problem Formulation

Initial Problem
\[
\min_{p(t)} \sum_{i=1}^{N} D_i \quad \text{s.t.} \quad p_i(t) \leq \gamma_i, \forall i \in N, \quad p(t) \in \mathcal{P}.
\]

Reformulated Problem
\[
\min_{p(t)} \sum_{i=1}^{N} f_i(t) \quad \text{s.t.} \quad f_i(t) = \lim_{t→∞} f_i(t), \quad p(t) \in \mathcal{P}.
\]

Min-Drift-Plus-Penalty Algorithm
The algorithm decides the power allocation by solving the following optimization problem at each time slot:
\[
\min_{p(t)} \sum_{i=1}^{N} f_i(t) + \sum_{i=1}^{N} X_i(t)y_i(t)
\]

Results and Conclusions
- Same performance with optimal EDF.
- Less power consumption.
- Handling packets of devices with limited power and satisfaction of average power constraints.
- Real-time low complexity algorithm.

Throughput Analysis for Relay-Assisted Millimeter-Wave Wireless Networks

Introduction and Motivations
- Millimeter-wave (mm-wave) communications can provide several Gbps of data rate, but they are characterized by high path loss and penetration loss.
- Relaying techniques can increase the reliability and throughput for mm-wave communications.
- The use of narrow beams for mm-wave communications may not allow the UEs to simultaneously transmit to both the relay and the destination (mm-wave access point, mmAP).

Contributions and System Model
- Random access mm-wave wireless networks assisted by a network cooperative buffer-aided full-duplex relay.
- Two different UE transmission schemes: broadcast and fully directional.
- Relay queue performance evaluation, throughput analysis and optimal transmission scheme.

Throughput Analysis

\[
T = NT_u = Nq_u(q_{su}T_u + q_uT_{su}) + Nq_u(T_{su} + T_{su})
\]

\[
T = Nq_uq_{su}T_u + Nq_uT_{su} + Nq_uT_{su} + Nq_uT_{su} + Nq_uT_{su}
\]

Number of UEs

Results and Conclusions
- The optimal transmission scheme (blue) depends on the angular distance.
- The UE-mmAP and the UE-Relay path lengths affect the optimal choice.
- It is not always beneficial to use narrow beams compared to wider beams.


Defining and Improving Test-case Quality

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Jürgen Börstler, Nauman bin Ali, Michael Unterkalmsteiner
SERL Sweden, Blekinge Institute of Technology

Research Plan

To achieve an effect in a situation apply this intervention

Approach to understand problem

Problem instances

1. Decision making in releasing software products based on input from testing
2. Confidence in testing
3. Maintenance of test suite in large-scale software systems

Evaluation approach

Experiment and case studies to evaluate the guidelines, tools

Solutions

- Test-case quality model
- Guidelines, templates for writing test cases
- Refactoring tool for test code

Approach to design solution

- SLR and interview study
- Study of Test code smells

Problems

Software quality assurance relies largely on software testing, of which fundamental units are test cases. Good test cases will increase the confidence in testing, and thereby assist product release decisions. Besides, the more software systems evolve, the more complex they become, which requires a larger number of additional test cases for quality checking. Therefore, the maintenance and evolution of test cases should be as important as the production code [2].

Therefore, my thesis work focuses on defining and improving test-case quality in the context of large-scale software-intensive systems while considering multiple dimensions including testing levels, human factors, automation level, etc.

Proposed Solutions

My first step is to build a quality model to provide a thorough definition of test-case quality. The inputs for building the model are from literature and practitioners.

Once having a definition of test-case quality, my next step is to use empirical methods in industrial contexts to:

1. Identify and evaluate requirements for achieving test-case quality (e.g., features in a programming language, tool support).
2. Identify means to operationalise the assessment of test-case quality (e.g., recommendations, guidelines or tool-support).
3. Identify means to facilitate co-evolution of test-code with production code.
4. Design and evaluate guidelines for test-case quality.

Systematic Literature Review

The objective of the SLR is to extract test-case quality characteristics, and their context such as testing levels, testing objectives, automation level, programming language, etc.

The initial quality characteristics, which are inspired by the ISO/IEC standard 25010:2011, will be matched to tentative dimensions as shown in Table 1.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Level</td>
<td>Unit, Integration, System, Acceptance, Alpha, Beta</td>
</tr>
<tr>
<td>Automation</td>
<td>Execution (manual / automated), Generation</td>
</tr>
<tr>
<td>Perspective</td>
<td>Developers, Testers, Test managers</td>
</tr>
<tr>
<td>Testing Objectives</td>
<td>Functional testing, Non-functional testing, Structural testing, Change related testing (confirmation testing, regression testing)</td>
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<tr>
<td>Quality</td>
<td>Process (of creating test cases), Product (test cases), In Use</td>
</tr>
<tr>
<td>Test case life cycle</td>
<td>Releasing Planning, etc.</td>
</tr>
</tbody>
</table>

Table 1: Possible dimensions of the test-case quality model

Interview Study

The objective of the interview study is to gain a better understanding of practitioners’ perceptions towards test-case quality. To achieve the above goal, I aim to answer the following questions in the interview study.

RQ1. How do practitioners define test-case quality?
RQ2. Where do practitioners get information regarding test-case quality?
RQ3. How do practitioners assess test-case quality?
RQ4. How well do perceptions of test-case quality align within a company?

Contribution

The contribution of my research is a thorough definition of test-case quality with a quality model that takes into account different perspectives in software testing.

Based on the definition, I will propose means to obtain high quality in test cases. They could be guidelines, recommendations, tools which will help practitioners to assess their test cases, to identify requirements for achieving high-quality test cases, and to facilitate co-evolution of test cases with production code.

Overall, these supports will allow companies to gain more confidence in testing, and thereby assist their product release decisions.

References


Deployment of Ad Hoc Network Nodes Using UAVs for Search and Rescue Missions

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As recently seen in a number of natural catastrophes such as hurricanes in Texas, Florida or Puerto Rico, major communication and electrical infrastructure is often knocked out. This leads to an inability to communicate between the victims and rescuers on the ground as well as between rescuers themselves. In this work we study the feasibility of using heterogeneous teams of UAVs to rapidly deliver and establish ad hoc communication networks in operational environments through autonomous in-air delivery of networking nodes called CommKits (Figure 1). Hardware and software infrastructures for autonomous CommKit delivery in addition to CommKit specification and construction is considered. The results of initial evaluation of two design alternatives for CommKits are presented based on more than 25 real flight tests in different weather conditions using a commercial small-scale UAV platform augmented with additional computational power and sensors.

CommKit Hardware Design

The design of the CommKit has been driven by a number of requirements:

- include communication means for setting up a communication infrastructure.
- light-weight/small size.
- standalone device containing its own electrical power, i.e. able to operate for a number of hours.
- capable of safe in-air delivery from a UAV.
- include computational resources and sensors – used for optimization and repair of the deployed network, self-monitoring and safe in-air delivery.

Initially two prototype CommKit units have been designed and developed with different components for evaluation purposes (i.e. internal/external parachute systems, WiFi access points). Their specifications are summarized in Figure 2.

CommKit Software Design

The software running onboard the CommKit’s Raspberry Pi computer is implemented using Robot Operating System (ROS, ros.org) allowing for easy integration with our existing UAV platforms. Two state machines depicted in Figure 3 were implemented using a real-time framework. They are responsible for controlling the Parachute Servo (PS) and the Release Servo Mechanism (RSM) of the CommKit. Both rely on a number of events which can be generated by software or physical switches.

Experimental Evaluation

Evaluation was performed over the course of four flight test days with more than 25 successful delivery missions using DJI Matrice 100 (1kg payload, up to 25 minutes of flight time). The main focus was to measure delivery accuracy for the two different parachute systems used (external and internal). Results are summarized in Figure 4.

Ongoing work

Ongoing work (Figure 5) focuses on the development of an algorithm for optimal communication node placement based on a 3D map of the environment as well as design of a new revised version of the CommKit unit based on the results of the initial experimental evaluation.


Figure 1. Scenario overview.

Figure 2. The CommKit hardware architecture (left) and the two test CommKit prototype units (right).

Figure 3. State machines used for controlling of the Release Servo Mechanism and the Parachute Servo of a CommKit.

Figure 4. Selected flight test experimental results. Two example real flight trajectories and the CommKits landing positions for 20 delivery missions (top). Measured acceleration magnitudes acting on a CommKit unit during a drop showing different stages of in-air deployment for CommKit0 and CommKit1, respectively (bottom).

Figure 5. Example optimization problem solution for optimal communication node placement problem (left). New CommKit prototype units (right).
a framework for compiling stream programs

Gustav Cedersjö, Jorn W. Janneck

Stream Computing Infrastructures

The result is a more efficient implementation, possibly at the expense of a larger program.
Stability Analysis

\[ L_i - \alpha J_i \leq \beta_i \]

\[ \delta_i = \beta_i - (L_i + \alpha J_i) \geq 0 \]
Stability-Aware Integrated Routing and Scheduling for Control Applications in Ethernet Networks

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3 General Motors R&D, Warren, MI, USA

Ethernet In Cyber-Physical Systems

- New and Emerging applications
- Infotainment and external connectivity
- Data recording and analytics
- Sensors and maps for driver assistance
- Consolidation and up-integration
- Sensing and actuation over Ethernet is rapidly growing
- Dominant network technology in automotive

Time Sensitive Networking (TSN) Ethernet

IEEE 802.1 Standard
Output port decides the route and the timed-gates decide the schedule of messages

System Model

- Periodic messages from sensors to controllers
- Forwarding delay (link)
- Transmission delay (switch)

Latency, Jitter

\[ h = \text{sampling period} \]
\[ L = R^b \] (Latency)
\[ J = R^w - R^b \] (Jitter)

Stability Analysis

\[ L_i - \alpha J_i \leq \beta_i \]
\[ \delta_i = \beta_i - (L_i + \alpha J_i) \geq 0 \]

Problem Formulation

- Given
  - Network characteristics (delays, topology)
  - Periods of each control application (released messages)
  - Controller & plant model (stability margin)
- Objectives
  - For each message in each switch determine:
    - Route: output port
    - Schedule: release time
  - Guarantee stability

Approach

- Constraints to be satisfied:
  - Network topology (routing)
  - No-loop (routing)
  - Path (routing)
  - No contention (scheduling)
  - Transposition (scheduling)
  - Stability (application)

Formulated in SMT (Satisfiability Modulo Theory)

Scalability Issue

<table>
<thead>
<tr>
<th>h_1</th>
<th>h_2</th>
<th>h_3</th>
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<tbody>
<tr>
<td>10</td>
<td>20</td>
<td>30</td>
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</tbody>
</table>

Hyper-period = 60

1.6% Unsolved
3% Unsolved
5% Unsolved

Experimental Results

35 nodes (10 sensor, 10 controller, 15 switches) and 60 test cases

Conclusions

- SMT formulation for joint Ethernet schedule-route synthesis
- Consideration of stability requirement
- Heuristics to improve synthesis efficiency

Bibliography

All digital PWM transmitters

M. T. Pasha, M. F. U. Haque(*), T. Johansson

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- Software-defined radio (SDR): fully digital radio, transmission of multi-band, multi-rate signals
- PA: most of the consumed power
- Switched-mode PA: higher efficiency, “digital” design, but no amplitude information, we need new transmitter architectures!
- Pulse-width modulation (PWM) is one alternative
- Carrier- based pulse-width modulation (CPWM) @IF
- Radio frequency pulse-width modulation (RF-PWM)
- PWM can be digitally implemented (D-PWM)

Example:
- The Modified Digital PWM Transmitter (MD-PWMT) combines digital PWM and outphasing
- All-digital implementation, does not require any analog components like DACs, phase modulators, and mixers
- Implemented in HDL in an FPGA
- FPGA offer signal processing using embedded processors, gigabit IOs and large embedded memory

Improved amplitude linearity

Measurement setup

Improved output spectrum

Haque, et al., to be presented at NORCAS18, Oct 30-31.

Project: 5G Wireless
Age of Information in Status Update Systems
Antzela Kosta, Nikolaos Pappas, Anthony Ephremides, Vangelis Angelakis, LIU

Introduction
• In many networking applications, fresh data is more important than stale data.
• The concept of Age of Information (AoI) quantifies the freshness of the knowledge we have about the status of a remote system.\[1\]

Research Question:
 How to provide a remote monitor with status update messages

Concepts
• Source: extracts samples from a stochastic process under observation.
• Medium: source-destination communication link.
• $\lambda$: average arrival rate of the generation process.
• $\mu$: average service rate of the transmission process.

Age defined. And our two supporting metrics \[2\]
The Age of Information (AoI) of the source $s$ at destination $d$ is defined as the random process
\[
\Delta(t) = t - u(t)
\]
$u(t)$: timestamp of the most recently received update

Cost of Update Delay (CoUD):
• The CoUD metric associates the cost of staleness with the statistics of the source
\[
C(t) = f_s(t-u(t))
\]
$f_s(t-u(t))$: monotonically increasing function that depends on the autocorrelation of the source

Value of Information of Update (VoIU):
• The VoIU captures the degree of importance of an update.
\[
V_i = D_i/D_i^t
\]

Case Study - System model \[3\]
• A cognitive network with a primary source - destination pair and a set of secondary pairs.

- Primary source: bursty traffic, secondary sources: saturated
- Primary and secondary access probabilities: $q_{pr}$ and $q_s$
- MPR capabilities at the receivers
- Rayleigh fading channels, error-free ACK, slotted time

Optimization formulation
• Maximize throughput subject to an age constraint
\[
\max_{q_{s}, q_{pr}} \mu_{total} \quad \text{subject to} \quad 0 \leq \Delta \leq \Delta_{\text{max}},
\]
$\mu_{total}$: aggregate throughput of secondary network
$\Delta$: AoI of the primary node
$\Delta_{\text{max}}$: average age limit the primary node can tolerate

Numerical Results

References
Using Crash Databases to Predict Effectiveness of New Autonomous Vehicle Maneuvers for Injury Reduction

Björn Olofsson¹,² & Lars Nielsen¹

¹Div. Vehicular Systems, Linköping University ²Dept. Automatic Control, Lund University

Introduction & Background

• Autonomous vehicle maneuvers in critical situations have high potential for reducing risk of injury or fatality in accidents.
• Method [1] for predicting the effectiveness of new, not yet existing autonomous vehicle-safety systems for injury reduction based on information available in crash databases.
• Lane-departure accidents in turns from the GIDAS database.

Crash Databases & Safety Systems

• Crash databases contain extensive information on previous real accidents that is well structured and could be extracted.
• Used both for retrospective studies for existing safety systems and predictive studies for estimating potential benefits of new safety system by emulation of the new control principle.
• Traditional active yaw control (AYC) with an alert and correctly acting driver steering along the road as well as the emerging new autonomous optimal lane-keeping control (O-LKC) considered, both relying on situation awareness.

Manageable Accidents & Mitigation Estimation

• Maximum velocity curves \(v_M\) give prediction of number of manageable \(N_M\) and non-manageable accidents \(N_{M\text{M}}\).
• Computed with numerical optimization of vehicle behavior in the turn using the software platform JModelica.org.
• Optimization of exit velocity \(v_f\) and initial velocity \(v_0\) gives the behaviors corresponding to AYC and O-LKC, respectively [2].

• Risk functions [3] used for predicting probability of a certain injury outcome, given departure velocity.
• Prediction of departure velocity \(v_D\) using optimization by iteratively increasing the lane width \(d\) until a solution is found for the \(N_{M\text{M}}\) non-manageable accidents for each system.

Computational Algorithm

• Monte Carlo approach with sampling from the risk functions \(K\) times results in probability distribution.
• \(N\) severe road-departure accidents extracted.
• \(N_B\) - number of mitigated accidents by optimal braking (velocity reduction).
• \(N_S\) - sum of accidents predicted manageable \((N_M)\) or mitigated \((N_B)\).

Results

• Maximum velocity curves for AYC and O-LKC give predicted manageable accidents (accidents below the \(v_M\) curves).
• Number of predicted manageable accidents \(N_M\) is 177 and 190 for AYC and O-LKC, respectively.
• Algorithm 1 gives \(N_B\) and \(N_S\) for each system, as well as an approximate distribution for the former \((K = 20000)\).

Conclusions

• Method performs effectively, gives interesting insights into relation between AYC and O-LKC, and demonstrates the potential of saved lives with autonomous maneuvers.
• Overall conclusion is that it is important to strive for the realization of autonomous vehicle safety systems.

References

On the search for industry-relevant regression testing research

Nauman bin Ali, Emelie Engström, Mohammad Mousavi, et al.
Blekinge Institute of Technology, Lund University, Halmstad University

Challenge

Context:
- Growing test suite (large-scale and heterogenous systems)
- Short time to market
- Continuous integration and deployment
- Importance of quick feedback

Need:
- Help to prioritize, select test cases and to minimize the test suite

Aim

Supporting operational decisions regarding selection, prioritization and minimization of regression test cases

Approach

Several systematic literature reviews
1068 papers

Results

Technological rules:

“To achieve <effect> in <context> apply <technique>”

TR 1: To reduce the regression test suite and testing time when regression testing large scale software systems utilize the following information attributes: #contributors of a piece of code, measured execution time, verdict, build type, variant under test and link to tested branch from test reports and fix time in issue reports. (This example was extracted from an evaluation of a tool called THEO [74].)

TR 2: To increase feature coverage, reduce testing time and improve fault detection capability when regression testing customisable, real-time systems, utilise information about verdicts and execution time in test reports. (This rule is based on the intersection of the classification of two different techniques, Multi-perspective prioritisation [38] and TEMSA [57], which have been evaluated in several studies [37, 38, 55–60].)

TR 3: To improve efficiency and effectiveness when regression testing large scale complex systems, utilise information about the test reports. (This rule is a generalisation of TR2 and is supported by the same studies and another two [17, 68].)
Optimised User Generated Content Management
MohammadHassan Safavi, Björn Landfeldt and Saeed Bastani

Aim
To optimally place content generated at the edge to minimise factors such as: energy usage, latency, bandwidth usage etc. This in contrast with the existing body of work on centrally generated content.

Approach
- Online learning of topological usage patterns (user social degree) using Machine Learning (sequential Bayesian learning)
- Error learning for estimatind content early demand rates
- Development of a novel online multidimensional knapsack algorithm for content placement
- Comparing online algorithms with offline optimization (Integer programming formulation).

System Model
Users belong to an ISP and the cost for accessing content is different if the content is stored at the local ISP, a Peering ISP or centrally in the Internet over a transit link.

Online Algorithms
We present the detailed multidimensional knapsack, and machine learning algorithms as follows:

Algorithm 1 Online Removable Content Placement Algorithm
Input: content and pool specific parameters: all request rates (dₜ) of each incoming content, and content size |b|
Output: Binary placement decision xₜ, 8n 2 N(i)
1. \[ dₜ > \frac{d}{2} \text{ if } 8c \text{ and } C \]
2. Update \( \hat{R} \)
3. Update \( S \)
4. \[ \epsilon \left( \frac{c_i + b_i}{c_i + b_i} \right) \text{ if } 8c \text{ and } C \]
5. for each content \( b \) arriving do
6. Predict \( \hat{d} \)
7. \[ \hat{d} \left( \frac{|b|}{d_{t+1} - d_{t+2} - d_{t+3} - d_{t+4}} \right) \]
8. \[ K \subset \{ b \} \]
9. \[ C \subset \text{sort}(K, e^{x_i}, \text{descending}) \]
10. \[ R, R \]
11. \[ S, S \]
12. while \( R, S \) do
13. \[ K \sim \text{first}(K) \]
14. \[ C, C \]
15. \[ R, R \]
16. \[ S, S \]
17. end while
18. let \( K \) be placed in central server
19. end for

Algorithm 2 Profile Learning Algorithm for user \( u \)
Input: Observe \( m^u \) at each \( t \)
Output: The estimated download rate and link distributions \( w^u \text{ and } v^u \)
1. \[ w^u = \text{Rand}(X) \]
2. \[ m^u = \left[ \begin{array}{c} t \end{array} \right] \]
3. \[ m^u = \left[ \begin{array}{c} 0 \end{array} \right] \]
4. \[ v^u = \left[ \begin{array}{c} 0 \end{array} \right] \]
5. for each observed \( m^u \) at the end of time-slot \( t \) do
6. \[ d^u = 0 \]
7. \[ w^u = m^u \]
8. for each \( k \) \[ 1 ... d^u \] do
9. \[ d^u = d^u + m^u \]
10. end for
11. \[ w^u = w^u + m^u \]
12. \[ c^u = 1 \]
13. \[ w^u = \text{f}^{-1}(d^u) \]
14. \[ w^u = w^u + \text{var}[d^u, w^u] \]
15. \[ m^u = [0 0 0] \]
16. end for

Selected Results
![User social degree learning accuracy](image)
![Overall profit based on user popularity distributions](image)
Safe Regression Test Selection for Modelica

Niklas Fors, Lund University

Problem
Running regression tests for the modeling language Modelica usually takes a long time. For example, running all tests for the Modelica Standard Library (MSL) takes 2-3 hours.

Contribution
We have defined a regression test selection technique that selects a subset of the tests to run after a change in order to save time. The technique is safe, meaning that all affected tests are run, but unaffected tests might run too.

Dependency Analysis
We analyze dependencies between classes to select test classes that need to run given a change.

Examples:
- If A is changed ⇒ run T1 and T2
- If B is changed ⇒ run T2

Models, functions, packages, etc., are all considered as classes.

Dependency Rules
We have defined dependency rules between classes:
Rule 1: A class has a dependency on an accessed class, including all parts of the qualified name.
Rule 2: A class has a dependency on its enclosing class.
Rule 3: A class that contains a redeclaration depends on all super classes and enclosed classes of the replacing class (and all their enclosed classes and super classes recursively).
Rule 4: A class has a dependency on implicitly called classes. This includes a record or type enclosing a function named equalityConstraint, and a class extending the class ExternalObject has dependency on enclosed function destructor.

Evaluation Results

<table>
<thead>
<tr>
<th></th>
<th>Modelica Standard Library</th>
<th>Heat Exchanger Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. testing runtime saved / changed class</td>
<td>95.5%</td>
<td>78.9%</td>
</tr>
<tr>
<td>Avg. testing runtime saved / changed file</td>
<td>88.9%</td>
<td>80.5%</td>
</tr>
<tr>
<td>Dependency analysis time</td>
<td>0.04%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

If a random class is changed in MSL, then we can save on average 95.5% of the testing time. If a random file is changed, then all classes in that file are considered as changed.

Verification
We have performed mutation testing on MSL to verify that our technique is safe. We performed mutations, like negating boolean conditions, to detect actual dependencies from test classes to mutated classes. If these dependencies were not found by our technique, then the dependency rules were incomplete or the implementation contained a bug. By mutation testing, we found six implementation bugs, generalized Rule 3 and found Rule 4.

Example of Rule 2

If we change B to extend A2 instead of A1, then M inside B.C will refer to A2.M instead of A1.M. Rule 2 captures this situation by creating a dependency from B.C to its enclosing class B.

Read more
- https://github.com/modelon/MCDTS - open source test suite for RTS
A Structured Linear Quadratic Controller

Martin Heyden, Richard Pates, Anders Rantzer
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Department of Automatic Control, Lund University, Sweden.

Problem Definition

We study a simple transportation problem on a line graph defined by the dynamics

\[
\begin{align*}
g'^{t+1} &= g'^{t} - \alpha q^t - r \cdot w^t, \\
r'^{t+1} &= r'^{t} + u^{t},
\end{align*}
\]

where \( g^{t} \) and \( r^{t} \) are goods and operations upstream of node \( k \), which is the sum of goods downstream of node \( k+1 \). \( k \) can be calculated by recursion through the graph:

- Receive \( f_{k-1} \).
- Calculate \( f_k = f_{k-1} + g^k + r^k \).
- Send \( f_k \) upstream.

The number of communication channels is proportional to the number of nodes. For a standard implementation, the number of communication channels are proportional to the square of the number of nodes.

Downside: The time to calculate the outputs also scale with the length of the graph.

Optimal Controller

LQ designed controllers are generally dense, making them unsuited both for synthesis and implementation on large scale systems.

For this problem we give an iterative formula for the optimal controller, which is sparse and structured:

\[
K_{k+1} = \begin{bmatrix}
\frac{1}{\eta} g^k & -I & 0 & \ldots & 0 \\
-1 & \frac{1}{\eta} K_{k+1} & \ldots & 0 \\
-k & -1 & \ldots & 0 \\
\end{bmatrix}
\]

With sparseness pattern

\[
\begin{bmatrix}
* & \cdots & * & \cdots & * \\
0 & \cdots & * & \cdots & * \\
0 & \cdots & * & \cdots & * \\
\end{bmatrix}
\]

\( \gamma \) can be calculated iteratively through the graph

\[
y_{k+1} = a \frac{q_k}{q_{k+1} + y_k} y_1 = a q_1.
\]

Proof Idea

We solve the Riccati equation recursively. For details, see [1]. Given a certain state space representation of the system, we show that the solution to the Riccati equation is given by

\[
X = \frac{1}{1-\eta} Y_k X^T + Q + X_N,
\]

where \( X_N \) is defined by the recursion:

\[
\begin{bmatrix}
0 & 0 & 0 & \cdots & 0 \\
0 & y_k & y_k X^T & \cdots & 0 \\
0 & y_k & y_k X^T & \cdots & 0 \\
\end{bmatrix}
\]

Simulation of Optimal Controller

The discount factor makes more goods available upstream.

References


This research was supported by the Swedish Research Council through the LCCC Linnaeus-Center and by the Swedish Foundation for Strategic Research through the project 59F RIT13-0001 SciPy. The authors are members of the LCCC Linnaeus Center and the KTH Excellence Center at Lund University.
A Radial Basis Function Method for Approximating the Optimal Event-Based Sampling Policy

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INTRODUCTION

In networked control systems it is desirable to have efficient wireless communication (saving energy and bandwidth) while still ensuring good control performance. By abandoning periodic sampling, communication can be made more efficient by sampling and updating the control signal only "when required" based on the system’s behaviour. This is the concept of event-based control.

In this work we consider the classic LQG problem with an added penalty $\rho$ on the average sampling rate $f$.

AN EQUIVALENT SETUP

The optimal structure has the equivalent representation [1]:

With the optimal controller structure known [1], the challenge is to find the optimal sampling policy. We extend the work in [2], and make the following contributions:

- Deriving an RBF method to approximate the value function and optimal sampling policy.
- Proving guaranteed existence and uniqueness of optimal RBF weights.
- Numerical validation of the proposed method.

The optimal policy is given by the relative value function $V(\tilde{x})$ of the problem.

**Optimal Policy:**
Sample when $V(\tilde{x}) = 0$.

$V$ satisfies the free boundary PDE:

$$\min\{\tilde{x}^T Q \tilde{x} + \tilde{x}^T A^T V + \frac{1}{2} \text{Tr}(R \nabla^2 V) - J, \rho + V(0) - V(\tilde{x})\} = 0.$$

THE OPTIMAL SAMPLING PROBLEM

We search for a threshold in the $\tilde{x}$-space, from which we reset $\tilde{x}$ to zero and accrue the cost $\rho$. This is an optimal stopping problem.

**Validation**

Analytic solution for $A = 0$:

$$V(\tilde{x}) = -\frac{1}{3} \max(2\sqrt{\rho} - \tilde{x}^T P \tilde{x}, 0)^2$$

REFERENCES


Scalable Optimization for Industrial Robots
Hamed Haghshenas¹, Anders Hansson¹, Mikael Norrlöf², Anders Robertsson² and Kristoffer Bergman¹
¹Linköpings Universitet, ²Lunds Universitet

Main Ideas and Contribution
- Time-optimal cooperative transportation of objects by multiple robots
- Path tracking
- Convex reformulation
- Promising results for two planar manipulators

Manipulator Dynamics
\[ \tau = M(q)\ddot{q} + C(q, \dot{q})\dot{q} + G(q) \]

Time-Optimal Path Tracking Problem
\[
\begin{align*}
\min \quad & T \\
\text{subject to} \quad & \tau(t) = m(s(t))s'(t) + c(s(t))s'(t)^2 + g(s(t)) \\
& s(0) = 0 \\
& s(T) = 1 \\
& s'(0) = s_0 \\
& s'(T) = s_T \\
& s(t) \geq 0 \\
& \tau(s(t)) \leq \tau(t) \leq \bar{\tau}(s(t)) \\
& \text{for } t \in [0, T]
\end{align*}
\]

Reformulation as Convex Problem
\[
\begin{align*}
\min \quad & \int_0^1 \frac{1}{B(s)} ds \\
\text{subject to} \quad & \tau(s) = m(s)a(s) + c(s)b(s) + g(s) \\
& b(0) = s_0^2 \\
& b(1) = s_T^2 \\
& b'(s) = 2a(s) \\
& b(s) \geq 0 \\
& \tau(s) \leq \tau(s) \leq \bar{\tau}(s) \\
& \text{for } s \in [0, 1]
\end{align*}
\]

Future Work
- Other constraints such as rate of torque change (non-convex)
- More realistic grasping
- More robots and distributed optimization

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Positioning based on BLE Proximity Measurements

Yuxin Zhao

High Level Research Challenges

- Trajectories estimation using optimal fusion of time series of position related data, e.g. proximity reports from Blue-tooth Low Energy (BLE)
- Parametric/Nonparametric spatial modeling
- Consider different relevant use cases via real data

Event-Triggered Proximity Reporting Procedure, BLE Example

Measurement Campaign and Propagation Model Fitting

Evaluation Results
Sensor-Based Trajectory Planning in Dynamic Environments

Andreas Westerlund$^{1,2}$, Giacomo Spampinati$^2$, Johan Löfberg$^1$, Hamed Hagshenas$^1$, Mikael Norrlöf$^{1,2}$

$^1$Linköpings Universitet - Dept. of E.E., $^2$ABB AB - Division of Robotics and Motion

Abstract

Traditional path planning of robotic manipulators uses the following structure:

- Path planning
- Trajectory generation
- Controller

In this work the Path planning and Trajectory generation steps are combined and an optimization solution is used. As a result, the path and the trajectory can be adapted to dynamic environments, for example tracking moving targets or avoiding moving obstacles. The solution is implemented and tested with a model of a SCARA robot.

Robot Model

The robot is a SCARA type manipulator with 2-DOF.

The dynamic model is given in the following form:

\[ \dot{q} = C(q, \dot{q}) + G(q) \]

where \( M(q) \) is the inertia matrix, \( C \) the Coriolis and centripetal terms and \( g \) the gravity vector.

An evaluation of the resulting algorithm is also performed using a dynamic model of a full 4-DOF SCARA robot to evaluate the actual computation time with a more complex dynamic model.

Optimal control problem

The combined path and trajectory planning problem can be solved using the following optimization formulation:

\[
\begin{align*}
\min_{\tau(t)} & \int_0^T L(q, \dot{q}, \tau, \dot{\tau}) \, dt \\
\text{s.t.} & \quad M(q(t))\ddot{q}(t) + C(q(t), \dot{q}(t))\dot{q}(t) + G(q(t)) = \tau(t) \quad \forall t \\
& \quad \tau_r \leq \tau(t) \leq \tau_u \\
& \quad q_l \leq q(t) \leq q_u \\
& \quad \frac{q(t)}{q(t)} \leq q(t) \leq \frac{q(t)}{q(t)} \\
& \quad p(0) = p_0, \quad \dot{p}(0) = p_0 \\
& \quad p(T) = p_T, \quad \dot{p}(T) = \dot{p}_T \\
\end{align*}
\]

Timed Elastic Nodes approach

To solve the optimal control problem partition the time interval into subintervals:

\[ 0 = t_0 \leq t_1 + \Delta t_1 = t_2, \]
\[ t_2 \leq t_3 + \Delta t_2 = t_3, \]
\[ \vdots \]
\[ t_{n-1} \leq t_n + \Delta t_{n-1} = t_n. \]

In each sub-interval the joint variables can be parameterized as cubic splines:

\[ q(t) = \xi_i(t) \quad \text{for} \quad t_k \leq t \leq t_{k+1}. \]

The state vector is defined as,

\[ \mathbf{x}(t) = \begin{bmatrix} q(t) \\ \dot{q}(t) \\ \dot{\xi}_1(t) \\ \dot{\xi}_2(t) \end{bmatrix}, \quad \mathbf{x}(t_k) = \begin{bmatrix} \xi_k(t_k) \\ \dot{\xi}_1(t_k) \\ \dot{\xi}_2(t_k) \end{bmatrix} \]

in addition the nodes and time intervals are combined into the timed elastic nodes,

\[ b_k = \{ x_1, \Delta t_1, x_2, \Delta t_2, \ldots, x_{n-1}, \Delta t_{n-1}, x_n \} \]

This leads to the discretized optimal control formulation,

\[
\begin{align*}
\min_{b_k} & \quad \sum_{k=1}^n \Delta t_k C_k \\
\text{s.t.} & \quad x_1 = x_1, \quad x_n = x_n, \quad x_{k+1} = x_k + \Delta t_k \dot{x}_k \\
& \quad y_k(t_k) \geq 0 \quad (k = 1, 2, \ldots, n-1). \\
\end{align*}
\]

Collision Avoidance

Assume the obstacle is below the robot arm and that only the end-effector needs to avoid the obstacle. Obstacles are modelled as spherical bodies,

\[ |(x, y) - (q_x, q_y)|^2 \geq (s + r)^2 \]

Results

The approach is evaluated in a test case with one obstacle. Computational times are provided for different cases, the cycle time was 4.5 sec.

Conclusions

- The planned trajectories are close to the optimal solution.
- The spline-based trajectory planner yield time continuous trajectories.
- Violations of the constraints between spline nodes.
- Current implementation is not real-time capable, with 4-DOF SCARA model 3.5 sec cycle was planned in 8.5 sec.

Future work

- Investigate alternative methods to the interior-point method.
- Alternative parameterizations of the splines.
- Improve the computational efficiency.

References

OMSimulator – Integrated FMI and TLM-based Cosimulation/Simulation with Composite Model Editing

ELLIT Project “Scalable Language Tools for Cyber-Physical Systems”
Lennart Ochel, Robert Braun, Adeel Asghar, Adrian Pop, Bernhard Thiele, Dag Fritzson, Peter Fritzson

Main Framework Aspects
Unified co-simulation/simulation tool
- FMI 2.0 (model exchange and co-simulation)
- TLM (transition line modelling) for numerically stable co-simulation
- Real-time and offline simulation

Research on dependency-graph-based master algorithms for parallel and multi-rate execution of FMI components

Standalone open source simulation tool with rich interfaces
- C/Java
- Scripting languages

Co-simulation framework as a solid base for engineering tools
- Integration into OpenModelica/Papyrus
- Open for integration into third-party tools and specialized applications (e.g. flight simulators, optimization tasks)

OMSimulator Architecture

General Composite Model Editor with 3D Visualization

Composite model editor with 3D visualization of connected mechanical model components which can be FMUs, Modelica models, etc., or co-simulated components

OMSimulator in OpenModelica 1.13.0
- Supports both FMI and TLM
- Both co-simulation and model exchange
- TLM connections are optional
- Co-simulation to multiple tools (Adams, Beast, Simulink, OpenModelica, …)
- Composite model editor
- External API interface and scripting
- Supports SSP (Structure and Systems Parameterization standard)
- Supports bus-connections

Architectural Aspects
- Composition of FMI and TLM model components
- Automatic partition of the system into pure FMI and FMI+TLM
- Single master and API for the entire framework
- Research on seamless integration of TLM and FMI

www.openmodelica.org
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SERP-Connect: a tool to support communication between researchers and practitioners

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The problem

Researchers and practitioners approach problems at different abstraction levels, from different perspectives, with different objectives, timeframes and using different methodologies.

Research papers are the most common way to communicate research results. However, all the results are not transferred to practitioners who face diverse challenges in their daily life.

Motivation

A better communication could be a win-win deal, practitioners can take advantage of research outputs ideally based on empirical evidence, while academics can test their solutions in practical environments, define new research projects and update the teaching.

The idea

SERP are the initials for Software Engineering Research and Practice. SERP-Connect has been designed to help to link research results with industry challenges in software engineering.

How to do this?

With SERP-taxonomy, a tool to support communication between researchers and practitioners.

SERP Taxonomy

Describe a research solution

Describe practical challenge/problem

SERP taxonomy allows classifying solutions and problems. Each entry either solution or challenge is classified according to SERP architecture describing the effect, intervention and scope. The facets of SERP-test are shown as example. The SERP-Test taxonomy.

When a total or partial coincidence occurs, then a research solution may support a challenge or problem. If the coincidence is partial, it means that there is a difference on one of the facets and it should be studied if it is still relevant or not.

Purpose of the tool

• To support the development of SERP-taxonomies
• To collect and match research results and practical challenges within different domains of software engineering
• To visualize research overviews based on SERP-classifications

The project is public available in GitHub. http://serpconnect.cs.lth.se/

What we have observed

We have seen how using SERP to describe challenges and solutions helps to better understand needs and communicate them. Also, that a visual representation helps to communicate and avoid misunderstandings.

How do you think that the communication between researchers and practitioners can be improved?

Would you like to see what people says about How to improve communication? We will like to see your comments and ideas. Please follow the the link. http://bit.ly/res-pra

References


How Much Will Tiny IoT Nodes Profit from Massive Base Station Arrays?

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Introduction
We study the benefits that Internet-of-Things (IoT) devices will have from connecting to a massive multiple-input, multiple-output (MIMO) base station. The main goal is to quantitatively answer the question “How Much Will Tiny IoT Nodes Profit from Massive Base Station Arrays?” specifically:

• How much can the transmit power of the tiny IoT nodes be lowered by using a multi-antenna base station?
• How much can the range be increased?

Background on Current IoT Solutions
Sigfox and LoRa are two proprietary IoT systems that mainly operate in the ISM bands around 868 MHz in Europe and 950 MHz in the USA.

LoRa
• uses a modulation technique based on chip spread spectrum (CSS) modulation
• uses 14 dBm of transmission power
• achieves a bit rate $R_s = \frac{D_B}{\tau}$ which depends on the bandwidth, $B$, and the spreading factor, $S$, of the signal
• has a chip rate of 1 chip/Hz
• has a bandwidth that ranges from 7.8 to 500kHz

Sigfox
• is an ultra narrowband (UNB) system
• operates with a bandwidth of only 100Hz
• uses 14 dBm of transmission power
• achieves a bit rate of only 100 bit/s
• uses differential-binary-phase-shift-keying modulation

System Model

Rate with Statistical Channel Inversion
When using statistical channel inversion power control,

$$\eta_k = \frac{\min \Phi_k / \Phi_0}{\max \Phi_k / \Phi_0}$$

the uplink rate $R_k(K)$ can be lower bounded as

$$\log_2 \left( 1 + \frac{M - 1}{1 + k_0 \rho_0 \beta \bar{a}_k} \right)$$

and upper bounded as

$$\log_2 \left( 1 + M \left( \frac{a \sqrt{\bar{a}_k}}{1 - k_0 \rho_0 \beta \bar{a}_k} \right)^{\frac{k}{k + 1}} \right)$$

where

$$a = 1 - \rho_0 \frac{1}{\beta} (\sqrt{\bar{a}_k} - \bar{a}_k)$$

and

$$k_0 = \frac{\rho_0 \beta \bar{a}_k}{1 + \rho_0 \beta \bar{a}_k}$$

Power Scaling
To find by which factor we can scale the transmitted power at the user by adding antennas at the base station we set up the equation

$$\log_2 \left( 1 + \frac{\rho_0 \beta \bar{a}_k}{1 + \frac{\rho_0 \beta \bar{a}_k}{M}} \right)$$

where

• $\bar{a}_k$ is in $\mathbb{C}_1$, one antenna at the base station
• $\bar{a}_k$ is in $\mathbb{C}^M$, $M$ antennas at the base station
• $\eta = \frac{\bar{a}_k}{\bar{a}_k}$

Simulation

• Single-cell system in a multi-cell world
  - Users dropped in a multi-cell world
  - Assigned to the base station to which the user has the smallest path loss including shadow fading
  - Only users assigned to the target cell are considered
• Large-scale fading, $\beta_k = -120.5 - 36.7 \log_{10}(d_k) - a_k$ (dB)
  - $d_k$ in the distance in kilometers
• Shadow fading, $a_k$ is normally distributed with zero mean and standard deviation of 6 dB
• Uplink SNR, $\gamma_k = 10 \log_{10} \left( \frac{P_k}{P_0} \right)$
  - $P_0$ (W), terminal radiated power
  - The noise figure and the antenna gains cancel out

Achievable Rate
Uplink rate assuming maximum ratio combining

$$C_{\text{MRC}} = \frac{\log_2 \left( 1 + \frac{\beta_k x_k^2}{\sum_{k^\prime \neq k} \beta_k x_k^2 + \eta_k} \right)}{2} = R_k(K)$$

where

$$\alpha = 1 + \rho_0 \frac{1}{\beta} (\beta_k - 1) \gamma_k$$

and

$$\eta_k = \frac{\rho_0 \beta \bar{a}_k}{1 + \rho_0 \beta \bar{a}_k}$$

Simulation Parameters
Simulation parameters for the UNB Sigfox-like scenario and the LoRa-like CSS scenario.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>UNB</th>
<th>CSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth, $B$</td>
<td>100 MHz</td>
<td>125 kHz</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>868 MHz</td>
<td>868 MHz</td>
</tr>
<tr>
<td>Terminal radiated power</td>
<td>14 dBm</td>
<td>14 dBm</td>
</tr>
<tr>
<td>Required rate</td>
<td>100 bps</td>
<td>366 bps</td>
</tr>
<tr>
<td>Coherence time</td>
<td>50 ms</td>
<td>50 ms</td>
</tr>
<tr>
<td>Coherence bandwidth</td>
<td>100 Hz</td>
<td>125 kHz</td>
</tr>
<tr>
<td>Coherence interval, $\tau_c$</td>
<td>5 samples</td>
<td>6250 samples</td>
</tr>
</tbody>
</table>

CSS Scenario

Conclusions
Tiny IoT nodes can profit from massive MIMO by
• spatially multiplexing many users at the same time
  - either lowering the transmitted power at the users, by at least a factor of $\frac{1}{\sqrt{M}}$
  - or increasing the range by up to 10% more than double with 100 antennas at the base station compared to a single-antenna base station

A new upper bound on the single-cell uplink capacity assuming maximum ratio combining and statistical channel inversion power control is presented, which is fairly tight for a large number of antennas in the base station.
Introduction and Background

Wireless power transfer from RF source to energy harvesting (EH) IoT

- Massive antenna array source: long range wireless power transfer (WPT)
- Accurate CSI is required at RF source for realizing full array gains
- Low cost hardware for economically viable ubiquitous deployment of IoT
- Low quality RF components are prone to hardware imperfections
- Significant EH performance degradation due to underlying in-phase and quadrature-phase imbalance (IQI) and its impact on CE errors

State of the art

- IQI generates a virtual image $i_{RX}$ of $N_{RX}$ at the multiantenna TX
- IQI estimation and compensation for MISO information transfer (IT)
- Degradation in DL IT performance due to joint IQI and CE errors
- Impact of CE errors on WPT from massive antenna TX with no IQI

Motivation

- Investigating the impact of IQI on efficacy of MU massive MISO WPT
- Rician fading model for incorporating strong LoS component in WPT
- More robust Least Squares (LS) based CE for TX precoder design

Key Contribution

- Obtain Rician channel estimate in MU massive MISO WPT under IQI
- Quantifying the degradation in optimized sum harvested power among EH users due to the joint IQI and CE (for LS and LMMSE) errors

System Description

- WPT from $N$ antenna RF source $S$ to the $M$ single antenna EH users $U$
- Flat quasi-static Rician block fading with coherence interval of $T$ samples
- $S \rightarrow U$ channel: $h_{j} = \frac{C_{j}}{\sqrt{N_{U}}} h_{0,j} + \frac{C_{j}}{\sqrt{N_{U}}} h_{R,j}, \forall j = 1, 2, \ldots, M$
- With channel reciprocity, DL CE using UL pilot transmission from users
- Baseband TX IQI in pilot matrix $S_{\phi}$ during UL transmission from $U$
- $S_{\phi} = T_{U} S_{I} + T_{U} S_{Q}$
- With diagonal matrices $[T_{U} S_{I}]$ and $[T_{U} S_{Q}]$
- $g_{U}$ and $\theta_{U}$ respectively denote the TX amplitude and phase mismatch
- Baseband RX IQI in received signal $Y$ at $S$ from $U$ during CE phase
- $Y_{U} = R_{S} Y_{I} + R_{S} Y_{Q}$
- With diagonal matrices $[R_{S}]$
- $g_{S}$ and $\theta_{S}$ respectively denote the RX amplitude and phase mismatch
- Received signal during CE phase with joint TX and RX IQI is given by
- $Y_{U} = H_{U} S_{I} + R_{S} H_{U} T_{U} S_{I} + R_{S} H_{U} T_{U} S_{Q} + W_{U}$
- More frequency independent IQI as narrow band signals in WPT and UL CE
- Limited feedback at $S$ from energy-constrained $U \rightarrow \text{no IQI compensation}$
- 2nd and 3rd terms in $Y_{U}$ represent interference and scaled noise due to IQI

Uplink Channel Estimation under TX-RX IQI

- The LS estimate $H_{U} \subseteq C^{N_{U}M}$ for the effective channel $H_{U}$ under IQI is
  $y_{U} = Y_{U} S_{I}^{(-1)} S_{Q}^{(-1)} = Y_{U} S_{i}^{(-1)} (2\pi f)^{-1}$
- $\bar{S}_{i}$ and $\bar{S}_{q}$ represent the time and power allocation during CE
- LMMSE can provide more accurate CE if CSI statistics known a priori
- LMMSE estimate $H_{U} \subseteq C^{N_{U}M}$ for $H_{U}$ can be obtained as
  $H_{U} = \hat{H}_{U} + \tilde{G}_{H_{U}} C_{U} \bar{y}_{U}^{(-1)} = \hat{H}_{U} - \mu_{U}^{(-1)}$
- $\mu$ and $C$ are used to represent respectively the means and covariances
- Using the channel estimate, $H_{U}$ or LMMSE $\hat{H}_{U}$, the optimal TX precoding maximizing the sum harvested power under IQI and CE errors is given by
  $x_{th} = \frac{\text{argmax}}{\|x\|} \left( H_{th}^{H} H_{th} \right)^{-1} \left[ \hat{H}_{U}^{H} y_{U} \right]$
- where $\mu$ as DL TX power and $v_{th}$ as $H_{th}^{H} H_{th} \subseteq C^{M \times M}$ representing the eigenvector corresponding to the largest eigenvalue $\lambda_{max}$

Downlink RF Power Transfer Under IQI and CE Errors

- Received energy signal at $U$ during DL WPT under TX IQI (i.e., $S$ IQI):
  $y_{th} = H_{th}^{H} (T_{U} x + T_{S_{h}} x_{h}) + w_{U}$

**Numerical Results**

- Quantify sum harvested power among users
- Five cases: 1. ideal (perfect CSI with no IQI), 2. IQI only, 3. users IQI, 4. RF source IQI, 5. Joint IQI
- IQI is a relatively minor concern
- IQI affects both UL CE and DL WPT
- Performance degradation due to joint IQI as compared to no IQI for LS & LMMSE based CE, respectively
- Sum EH degradation is much higher for the LS based CE compared to LMMSE
- IQI and CE errors jointly can lead to about 30% degradation in achievable gains
- $U \rightarrow$ IQI being a minor concern, enables to have cheaper hardware at EH-IoT nodes
- More than 10% degradation in sum EH due to IQI alone without any CE errors

Concluding Remark

As IQI may cause significant EH performance degradation than CE errors alone, it needs to be compensated at massive antenna source for realizing the full energy beamforming gains

Selected References