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Publishable Summary

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Project coordinator name:
Dr. Christophoros Nikou

Project coordinator organisation name:
PANEPISTIMIO IOANNINON

This project is concerned with the cross-layer optimization of wireless visual sensor networks that are based on Direct Sequence Code Division Multiple Access (DS-CDMA). Sensor networks are comprised of typically low-weight distributed sensor nodes that can communicate with each other and/or with a centralized control unit. In this project, we are interested in visual sensor networks, where each node is equipped with a video camera and transmits video information. Most of the previous work on sensor networks has focused on networks that transmit scalar information such as temperature, pressure, acoustic data, etc.

The OSI (Open Systems Interconnection) Reference Model includes seven layers that were originally designed so that the information flow between them could be minimal. Thus, each layer could be optimized independently. However, recent research has shown that the joint optimization of the network layers can significantly improve performance, especially for the case of wireless networks. This is the concept of cross-layer optimization. Most of the previous research only considers a subset of the OSI layers in the optimization. In this work, we have implemented cross-layer optimization in wireless visual sensor networks, considering the whole range of layers, from the physical to the application layer.

In the proposed wireless visual sensor network, each visual sensor node transmits using DS-CDMA. In a DS-CDMA system, all users are transmitting simultaneously over the same bandwidth. Their transmissions are distinguished through the use of different spreading codes. Even if the spreading codes used are orthogonal to each other, transmissions of one node cause interference to the other nodes, due to possible asynchronous transmissions and multipath fading. Clearly, a single visual sensor node can improve the quality of the received video by increasing its transmission power. However, this also increases the interference to the other sensor nodes and affects their received video quality. Thus, we can say that the visual sensor nodes have to compete for network resources. The final solution results from an agreement between the visual sensor nodes. We propose to apply Game Theory to determine the resource allocation between the visual sensor nodes.

The length of the project is four years. We next summarize the work performed during the project.

We have developed a computer simulation of a DS-CDMA wireless visual sensor network that uses Minimum Total Square Correlation spreading codes and Auxiliary Vector filtering for detection.

We have also developed a cross-layer optimization scheme that determines the transmission power, source coding rate and channel coding rate, such that either the average video distortion of the nodes or the maximum distortion among the nodes is minimized. A discrete optimization problem was solved (all parameters were chosen from appropriate discrete sets). We also extended the scheme to allow for the transmission powers of the nodes to take continuous values within a pre-specified range, whereas the source and channel coding rates still take discrete values. The resulting mixed-integer optimization problem was solved using Particle Swarm Optimization. We also developed a cross-layer optimization scheme that solves the same resource allocation problem using a criterion based on the Nash Bargaining Solution from Game Theory instead of minimizing the average or maximum distortion.

We also investigated the use of multirate DS-CDMA in wireless visual sensor networks. We considered a single–cell system where each node uses the same chip rate, but can transmit at a different bit rate. The proposed cross–layer scheme enables the Centralized Control Unit (CCU) to jointly allocate the transmission power, the transmission bit rate and the source–channel coding rates for each VSN node in order to optimize the delivered video quality. The transmission power of each visual sensor assumes values from a continuous range, while the rest of the resources take values chosen from an available discrete set.

Furthermore. we developed a resource management scheme for wireless visual sensor networks that is based on individual video characteristics and uses the Nash bargaining solution. The visual sensors monitor different scenes of varying motion levels, thus different network resources need to be allocated to each sensor. For each recorded scene, our approach considers its individual content-related parameters, in contrast with previous methods that group the sensors according to the amount of motion present in the scene and assign the same transmission parameters to all members of a group. Based on quality-driven criteria (under the constraint of constant chip rate), we allocate to each node a suitable continuous power level, a discrete source coding rate and a discrete channel coding rate. The resulting problem is solved using the Particle Swarm Optimization algorithm.

We also considered the use of the Kalai-Smorodinsky bargaining solution from Game Theory in the optimization problem instead of the Nash bargaining solution. The Kalai-Smorodinsky bargaining solution is an alternative to the Nash bargaining solution and is based on four axioms. The first three axioms are the same as the axioms that are fulfilled by the Nash bargaining solution. The fourth axiom is the axiom of Individual Monotonicity and replaces the axiom of Independence of Irrelevant Aternatives that is fulfilled by the Nash bargaining solution. Instead of solving a mixed-integer optimization problem as in the Nash bargaining solution, we obtained the Kalai-Smorodinsky bargaining solution geometrically. Our experimental results showed that the Kalai-Smorodinsky bargaining solution results in lower power levels compared to competing optimization criteria.

Furthermore, we considered the use of clustering for the resource allocation. We assumed a centralized topology where each sensor transmits directly to a Centralized Control Unit (CCU), which manages the network resources. In real environments, the visual sensors view and transmit scenes with varying amount of motion. Thus, each recorded video has its individual motion characteristics. Our aim is to enable the CCU to jointly allocate the transmission power and source–channel coding rates for each WVSN node under certain quality–driven criteria and constant chip rate. We considered two approaches for the cross–layer optimization scheme. In the first, the optimal set of network resources is assigned to each node according to its individual motion characteristics. In the second approach, the nodes are partitioned into clusters according to the amount of motion in the recorded scenes. Then, all nodes within a cluster are assigned identical network resources. Both approaches result in mixed–integer optimization problems, which are solved with the Particle Swarm Optimization algorithm.

The project website URL is: http://www.cs.uoi.gr/~lkon/clovisen.