

Smart Communication in a Wired Sensor- and Actuator-Network of a Modular Robot Actuator System Using a Hop-Protocol with Delta-Routing

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Communication in Sensor Networks

- Communication gains impact with increasing **miniaturization** and densities in sensor- and actuator networks, especially in the context of **robotics** and **sensorial materials** - they require basically **wired networks**
- The **network topology** of sensor- and actuator networks is in generally **distributed and decentralised**, and nodes of such a network have different computing power and storage, resulting in the following constraints and **requirements** for protocol design:
 1. **message-based point-to-point communication**,
 2. application-specific **scalable protocol** regarding network and data sizes to satisfy A. low-power design, and B. reducing computing and storage requirements,
 3. **no** unique node **addressing** (not usable in high density sensor networks),
 4. **simple routing** strategies, and finally
 5. **reliability** and **robustness** against link failures, requires alternative path finding.
- Development of a Scalable Communication Protocol SLIP satisfying low-resource and low-power demands featuring implementation both in hardware (ASIC/FPGA technology) and software.**
- System-On-Chip design** on Register-Transfer-Logic (RTL) level using FPGA and ASIC technologies enables
 1. small-sized integration of sensors and data processing units (DPU) scaled down to one-chip designs using ASIC- and MEMS technology, and
 2. low-power design, required especially for high-density sensor networks sourced by environmental energy (energy harvesting).

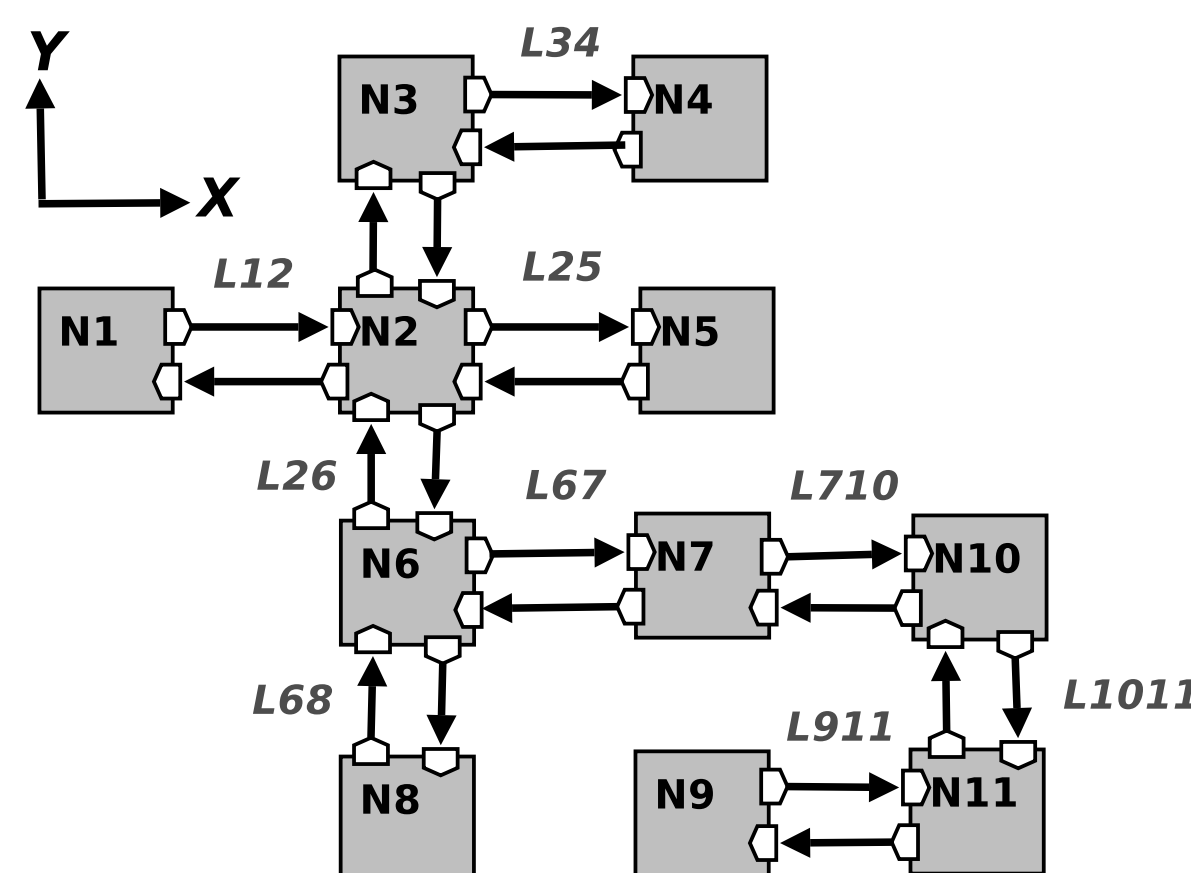


FIGURE 1: An example network (ADC=2) with an irregular topology connected by bidirectional point-to-point links.

ModuACT: a Modular Robot Actuator with Integrated Sensorial Materials

- The design of the modular robot actuator (figure 2) is based on previous projects designing bio-inspired multi-legged autonomous (walking) robots [1], and it is used for a **demonstrator** of new **sensorial materials, technologies, and sensor data processing**.
- The **robot actuator** consists of a rotational joint drive, control and data processing electronics using a FPGA, four **bidirectional communication links** (physical layer: LVDS).
- The control and data processing system is implemented entirely in digital logic and RTL as a **SoC-design** using a communicating sequential multi-process programming model and the **ConPro high-level synthesis framework** [2] on behavioural level.
 - ◆ Highlevel-synthesis: 4000 lines ConPro source code, synthesized to 40000 lines VHDL,
 - ◆ Gatelevel-synthesis: about 300k gates with LSI_10k ASIC library, 15000 LUTs in Xilinx Spartan III FPGA.
- There are sensors inside the actuator (position, current, temperature) and outside distributed around interconnection elements (strain gauge sensors).

Several actuators and sensor units can be connected in a network building a robot manipulator arm or a leg of a walking robot [1].

- **Array of strain gauge sensors printed on interconnection elements** using functional printing process technology [3], see figure 2.
- One or more sensors are connected to a Digital Processing Unit (DPU). Each DPU implements data processing and communication using the SLIP protocol.

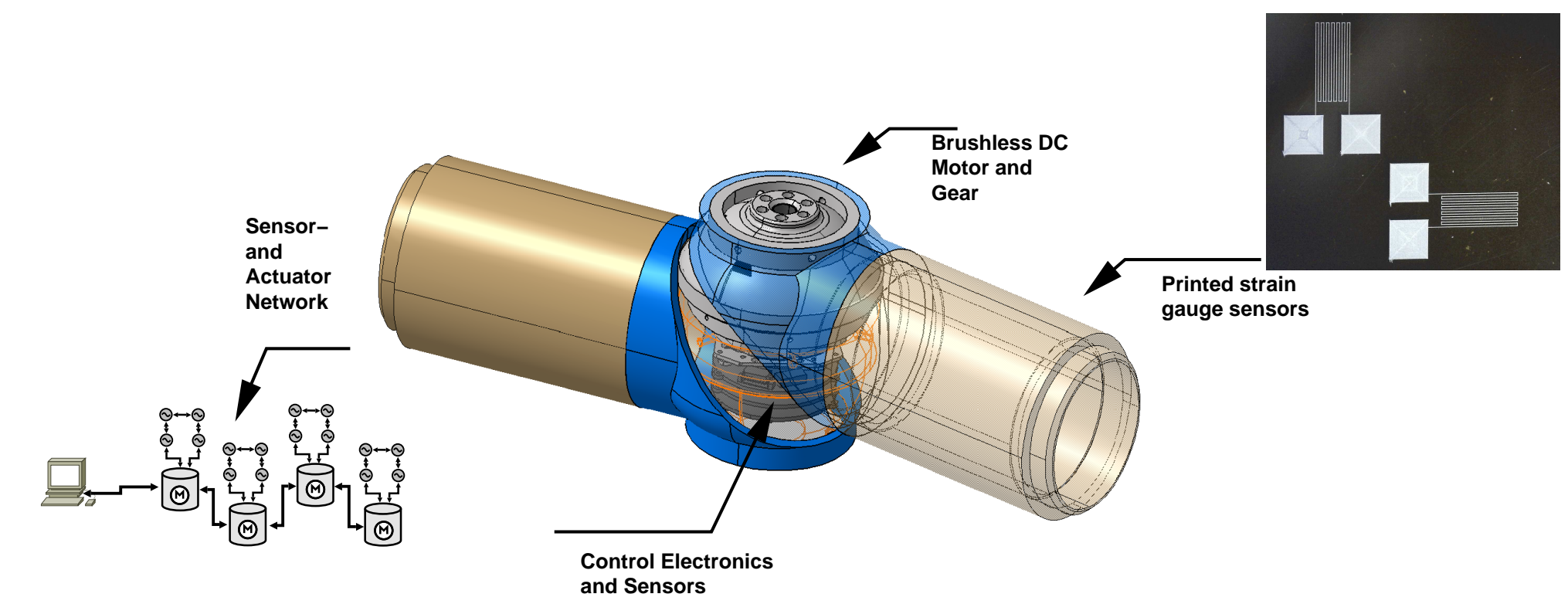


FIGURE 2: The Modular Robot Actuator Joint with internal and external sensors forming a sensor- and actuator network. Strain gauge sensors can be printed on a film using silver-ink and aerosol techniques [3].

SLIP: a Scalable Local Intranet Network Protocol

- **SLIP** is scalable with respect to network size (**address size class ASC**, ranging from 4 to 16 bit), maximal data payload (**data size class DSC**, ranging from 4 to 16 bit length) and the network topology dimension size (**address dimension class ADC**, ranging from 1 to 4)
- Network nodes are connected using (serial) point-to-point links, and they are arranged along different metric axes of different geometrical dimensions (ADC=1: chain, ADC=2: meshnet, ADC=3: cube...), see figure 1.
- Regular and irregular networks (with missing nodes and links) are supported for each dimension, a **node is both a Network Service Endpoint and a router**, using smart routing rules, see figure 3, to solve for example backend-traps (Path N1-N9 in figure 1).
- Communication implements message passing, the destination is specified by a relative **Δ -distance vector** (hop-count for each dimension), avoiding unique and absolute node addressing.
- A message packet contains a **header descriptor** HDT specifying the type of the packet and the scalable parameters ASC, DSC and ADC.
- A **packet descriptor** PDT follows the header descriptor, containing: the original and actual Δ -vector modified by routing, a backward-propagation vector Γ , a preferred routing direction ω and the length of the message.
- Implementation of protocol stack in hardware making a **SoC-design** using a communicating sequential multi-process programming model and the **ConPro high-level synthesis framework** [2] on behavioural level:
 - ◆ Highlevel-synthesis: 3000 lines ConPro source code, synthesized to 30000 lines VHDL,
 - ◆ Gatelevel-synthesis: about 100k gates with LSI_10k ASIC library, 9000 LUTs in Xilinx Spartan III FPGA.

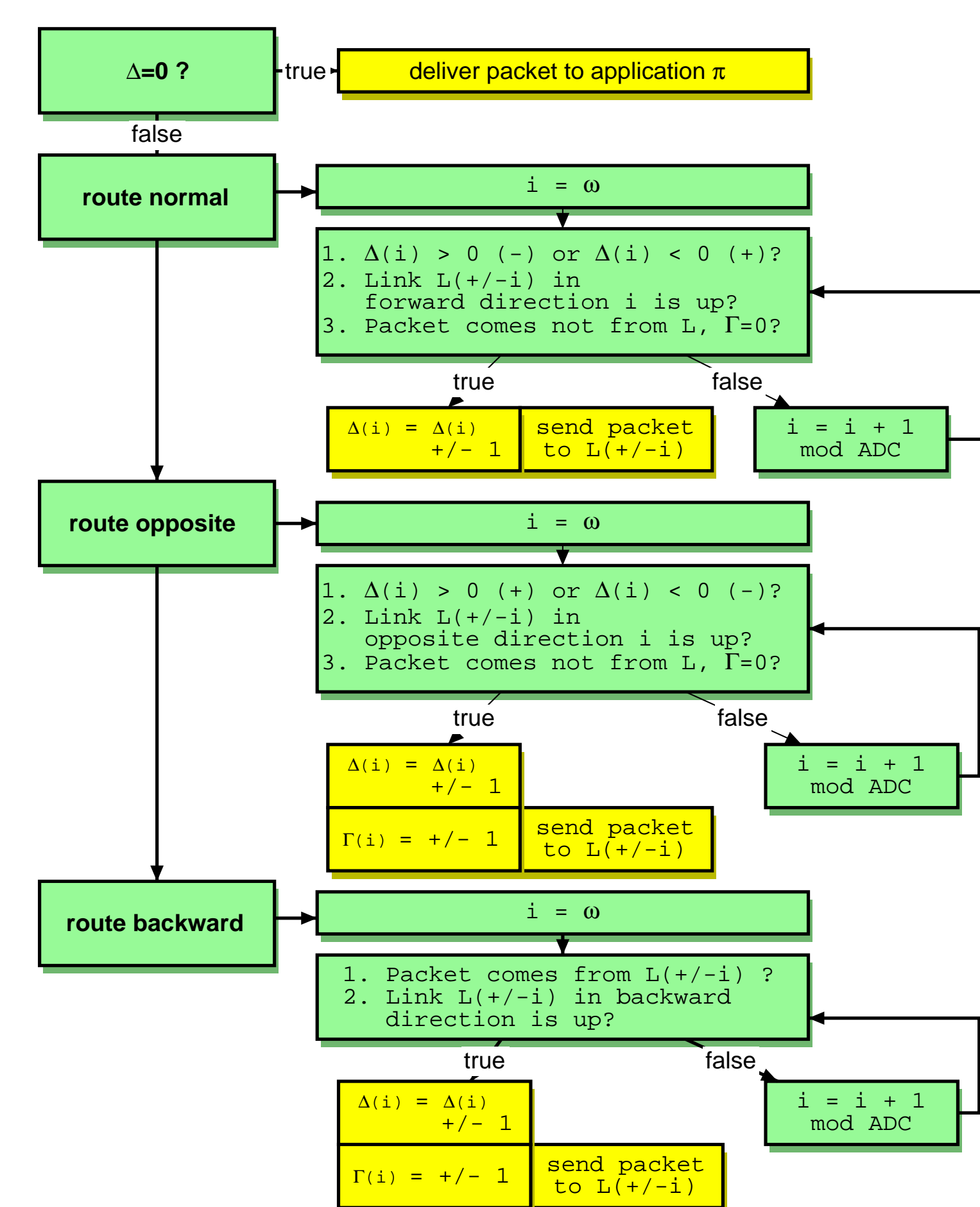


FIGURE 3: Simplified processing of incoming packets with smart routing using different rules (either from incoming link L or application layer π). Rule selection depends on packet descriptor contents.

Bibliography

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