Bernd-Ludwig Wenning

Context-Based Routing in Dynamic Networks

VIEWEG+TEUBNER RESEARCH

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Preface

Now that the work on this thesis comes to an end, it is time for some personal words.

First of all, I would like to thank Prof. Dr. Carmelita Görg for providing me the position as a research assistant in her working group and thereby giving me the opportunity to do the research work that led to this thesis. As significant parts of this thesis are based on research work that I did for subproject B1 of the Collaborative Research Center (CRC) 637, I also express my thanks to Prof. Dr. Bernd Scholz-Reiter as the speaker of this CRC and as the subproject leader in cooperation with Prof. Dr. Görg.

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Research is best done in a team of colleagues with whom ideas can be developed and discussed. I hereby express my thanks to all people I have worked with during my time at ComNets, in the CRC 637 and at CIT, especially to Markus Becker and to Henning Rekersbrink.

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Last but not least, special thanks go to my friends, my parents, my sister, and my brother for all their mental support in the past years.

Bernd-Ludwig Wenning

Abstract

In communication networks as well as in logistic networks, methods to find an efficient path from a source to a destination are of major importance. In the former, data has to be transmitted from a sender to a receiver, while in the latter, goods have to be delivered from their origins to destinations. The methods to determine the paths through such networks are generally referred to as *routing methods*.

The topic of this thesis is positioned in this area of routing methods, more specifically in the area of routing based on current context. The routing approach developed in this thesis is applied to both application domains: *communication networks* and *logistic transportation networks*.

In both domains, there can be specific contexts or pieces of context information that influence the choice of routes. This thesis presents a novel routing approach with a generic formulation for context-based multi-criteria routing, which includes the routing message exchange concept as well as the decision function used to select routes. The generic formulation is then specialised for the two mentioned application domains, resulting in the Distributed Logistic Routing Protocol (DLRP) on the logistic side and the Reactive Environmental Monitoring Aware Routing (Reactive EMA) for wireless sensor networks on the communication networks side. In the core of both protocols, the Multi Criteria Context-based Decision (MCCD) system is applied, which is a major aspect of this thesis.

Analytical investigations on the volume of messaging that is generated by the routing protocol are presented. These investigations show the need for methods to prevent heavy routing message flooding. A combination of two flood limiting methods is proposed: The use of fixed hop limits plus the discarding of routing messages based on intermediate route evaluations. It is shown that these methods have a high potential to reduce the routing traffic.

For evaluation of the routing protocols, simulations were run in both domains and the results are presented. In the logistic domain, a topology based on a map of Germany with major cities and highway connections between them is used as evaluation scenario. The routing algorithm shows good performance within the scenario, especially with respect to vehicle utilisation and travelled distances. The routing traffic reduction introduced in the analytical part is also proven in the logistic simulation.

In the wireless sensor network domain, a scenario is used where the sensor nodes are threatened to be destroyed by the phenomenon they sense, which is a fire in the investigated scenario. As the sensors are supposed to monitor temperature, they can detect the fire but eventually get destroyed and therefore can neither sense nor relay any data afterwards. Reactive EMA is designed to consider this during the route selection, so that high temperature nodes are avoided as relay nodes, thus increasing the route reliability. For evaluation, Reactive EMA is compared to a proactive variant (Proactive EMA) and to the conventional AODV and OLSR routing protocols. In comparison to AODV and OLSR, Reactive EMA shows advantages, while Proactive EMA achieves comparable or better performance in some aspects.

Kurzfassung

Sowohl in Kommunikationsnetzen als auch in logistischen Netzen sind Verfahren zur Suche eines effizienten Wegs von einer Quelle zu einer Senke von großer Bedeutung. In Ersteren sind Daten von einem Sender zu einem Empfänger zu übertragen, in Letzteren sind Güter von Ursprungsorten zu ihren Zielorten zu transportieren. Die Verfahren zur Ermittlung der Wege durch solche Netze werden allgemein als *Routingverfahren* bezeichnet.

Das Thema dieser Dissertation ist im Bereich dieser Routingverfahren angesiedelt, spezifischer im Bereich des Routings auf Basis eines aktuellen Kontextes. Das in dieser Arbeit entwickelte Routingverfahren wird auf die folgenden beiden Anwendungsgebiete angewandt: *Kommunikationsnetze* und *transportlogistische Netze*.

In beiden Anwendungsdomänen können spezifische Kontexte oder Kontextinformationen existieren, die die Wahl der Routen beeinflussen. Diese Dissertation stellt einen neuen Routingansatz vor, der eine allgemeine Formulierung für kontextbasiertes, multikriterielles Routing beinhaltet. Diese Formulierung umfasst sowohl das Konzept des Austauschs von Routingpaketen als auch die für die Routenwahl verwendete Entscheidungsfunktion. Dieser allgemeine Ansatz wird für beide Anwendungsgebiete konkretisiert und resultiert dort im *Distributed Logistic Routing Protocol* (DLRP) auf Seiten der logistischen Netze und im *Reactive Environmental Monitoring Aware routing* (Reactive EMA) für drahtlose Sensornetze als Untermenge der Kommunikationsnetze. In beiden Protokollen wird die *Multi Criteria Context-based Decision function* (MCCD), die ein wesentlicher Teil dieser Arbeit ist, eingesetzt.

Der analytische Teil dieser Dissertation beinhaltet Untersuchungen zum durch das Routingprotokoll erzeugten Kommunikationsvolumen. Diese Untersuchungen zeigen die Notwendigkeit von Methoden zur Vermeidung großer routinginduzierter Kommunikationsvolumina auf. Eine Kombination zweier Methoden wird vorgeschlagen: Die Verwendung von festen Hop Limits und das Verwerfen von Routingnachrichten auf der Basis von Zwischenbewertungen der Route. Es wird gezeigt, dass diese Methoden ein großes Potential zur Beschränkung des Kommunikationsvolumens aufweisen.

Zur Bewertung der Routingprotokolle wurden für beide Anwendungsdomänen Simulationen durchgeführt, deren Resultate in dieser Arbeit präsentiert werden. In der Transportlogistik wurde eine Topologie verwendet, die auf einer Deutschlandkarte mit Großstädten und Autobahnverbindungen dazwischen basiert. Der vorgestellte Routingalgorithmus führt in diesem Szenario zu guten Ergebnissen, insbesondere in Bezug auf die Auslastung der Fahrzeuge und die gefahrenen Entfernungen. Darüber hinaus wird die Methode der Beschränkung des routinginduzierten Kommunikationsvolumens ebenfalls durch Resultate der Logistiksimulation positiv validiert.

Im Bereich der drahtlosen Sensornetze wird ein Szenario verwendet, in dem die Sensoren durch das Phänomen, das sie wahrnehmen, zerstört werden. Im verwendeten Szenario ist dieses Phänomen ein Feuer. Die Sensoren überwachen die Temperatur, daher können sie das Feuer wahrnehmen. Sie werden dann aber bald zerstört und können danach weder messen noch Daten weiterleiten. Reactive EMA berücksichtigt dies bei der Routenwahl, so dass vermieden wird, Sensorknoten, die einer hohen Temperatur ausgesetzt sind, als Weiterleitungsknoten in Routen zu verwenden. Zur Bewertung wird das Reactive EMA mit einer proaktiven Variante (Proactive EMA) und den konventionellen Protokollen AODV und OLSR verglichen. Im Vergleich zu AODV und OLSR hat Reactive EMA klare Vorteile, während Proactive EMA im Vergleich zu Reactive EMA in einigen Aspekten gleich gute oder bessere Leistung zeigt.

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List of Abbreviations

AODV Ad-hoc On-demand Distance Vector
APTEEN Adaptive Periodic Threshold-sensitive Energy-Efficient sensor Network protocol
ASC Aspect-Scale Context
BGP Border Gateway Protocol
CAR Context-Aware Routing protocol
cdf Cumulative distribution function
C^2E^2S Cluster and Chain based Energy*delay Efficient routing Scheme
CNCL Communication Networks Class Library
CoOL Context Ontology Language
CVRP Capacitated Vehicle Routing Problem
DLRP Distributed Logistic Routing Protocol
DSDV Destination-Sequenced Distance Vector
DSR Dynamic Source Routing
DYMO Dynamic MANET On-demand routing
EGP Exterior Gateway Protocol
EM-GMR Energy and Mobility-aware Geographical Multipath Routing
EMA Environmental Monitoring Aware routing
GMR Geographical Multipath Routing
GPS Global Positioning System
HEED Hybrid Energy-Efficient Distributed routing
ID Identifier
IEEE Institute of Electrical and Electronics Engineers
IGP Interior Gateway Protocol
LAN Local Area Network
LEACH Low-Energy Adaptive Clustering Hierarchy
LEACH-C Centralised LEACH
LSP Logistic Service Provider
LoCoSim Logistics and Communication Simulator
MANET Mobile Ad-hoc Network
MCCD Multi-Criteria Context-based Decision
MCP Multi-Constrained Path
MCR Multi-Criteria Routing protocol
MTSP Multiple Traveling Salesman Problem
mu monetary units

NWAUF	Normalized Weighted Additive Utility Function
OLSR	Optimized Link-State Routing
OSPF	Open Shortest Path First
OWL	Ontology Web Language
PAN	Personal Area Network
PDP	Pickup and Delivery Problem
PDPTW	Pickup and Delivery Problem with Time Windows
PEGASIS	Power-Efficient Gathering in Sensor Information Systems
RDF	Resource Description Framework
RIP	Route Information Protocol
RN	Route Notification
RREQ	Route REQuest
RSSI	Received Signal Strength Indicator
SCAR	Sensor Context-Aware Routing protocol
SINR	Signal to Interference and Noise Ratio
SPIN	Sensor Protocol for Information via Negotiation
TDMA	Time Division Multiple Access
TEEN	Threshold-sensitive Energy-Efficient sensor Network protocol
TSP	Traveling Salesman Problem
tu	time units
VRP	Vehicle Routing Problem
VRPTW	Vehicle Routing Problem with Time Windows
WSN	Wireless Sensor Network
XML	eXtensible Markup Language

List of Symbols

Symbol	Area	See Page	Meaning
a_j	NWAUF	46	route alternative corresponds to j in the context notation
C_i	Context notation	23	context criterion i
C_{Prob}	HEED	13	preset cluster head percentage
CH_{Prob}	HEED	13	probability to become a cluster head
c	McCarthy context logic	19	(inner) context within McCarthy's context logic
c'	McCarthy context logic	19	outer context within McCarthy's context logic
c_i	Context notation	23	current value of C_i, according to S_i
$c_{i,j}$	MCCD	52	value of c_i for decision alternative j
$c_{i,min}$	Context notation	23	minimum possible value of C_i
$c_{i,max}$	Context notation	23	maximum possible value of C_i
$D_{Prop,l}$	Routing traffic analysis	69	Route request propagation depth on a path of length l
d_{route}	MCCD example	55	Delay on route
E_{max}	HEED	13	maximum energy of a node
$E_{residual}$	HEED	13	remaining energy of a node
E_{route}	MCCD example	55	Energy consumption on route
$f_{i,j}$	NWAUF	46	current value of criterion i for route alternative a_j corresponds to $c_{i,j}$ in the context notation/MCCD
$f'_{i,j}$	NWAUF	46	normalised value of criterion i for route alternative a_j

Symbol	Area	See Page	Meaning
$f_{i,min}$	NWAUF	46	minimum value for criterion i corresponds to $c_{i,min}$ in the context notation
$f_{i,max}$	NWAUF	46	maximum value for criterion i corresponds to $c_{i,max}$ in the context notation
$f_{s,i}(c_i)$	Context notation	23	scaling function for values c_i, $f_{s,i}$ is a specialisation of I_i
G	LEACH	12	Group of nodes not having served as cluster head in the last $1/P$ time intervals
G	MCCD example	55	Node group membership
$I_i(c_i)$	Context notation	23	context interpretation rule for value c_i of criterion C_i
$ist(c,s)$	McCarthy context logic	19	McCarthy's context logic: statement s is true in context c
j	Context notation	23	decision alternative
K	Routing traffic analysis	59	Number of edges at a node (node degree)
k	C^2E^2S	48	Maximum hop distance to cluster head
$\mathbf{L}$	Routing traffic analysis	69	Set of route forwarding limits
l	Routing traffic analysis	60	Route length
l_{max}	Routing traffic analysis	62	Maximum path length
N	Routing traffic analysis	59	Number of nodes in a network
n	LEACH	12	Node ID
$n_{notinc,l}$	Routing traffic analysis	61	Number of links in a path of length l that are not included in shorter paths
$n^*_{notinc,l}$	Routing traffic analysis	68	Number of links in a path of length l that are not included in shorter paths when using route request hop limits
n_{paths}	Routing traffic analysis	58	Number of paths between two nodes
n_{RREQs}	Routing traffic analysis	59	Number of route requests being sent in one route discovery

Symbol	Area	See Page	Meaning
P	LEACH	12	Target percentage of cluster heads
$P_{inc,m}$	Routing traffic analysis	61	Probability that a subpath of length m from a path of length l is included in paths with a length shorter than l
P_{link}	Routing traffic analysis	60	Link existence probability
P_{path}	Routing traffic analysis	60	Path existence probability
$P_{valid,l}$	Routing traffic analysis	69	Validity probability for a path of length l
p	C^2E^2S	48	optimal probability to become a cluster head
r	C^2E^2S	48	communication range
r	LEACH	12	Cluster head selection round
S_i	Context notation	23	scale (unit) in which C_i values should be given
s	McCarthy context logic	19	statement within McCarthy's context logic
$T(n)$	LEACH	12	Threshold for cluster head selection
T_C	APTEEN	13	Time count
$U(a_j)$	NWAUF	46	Normalized Weighted Additive Utility Function for route alternative a_j corresponds to U_j in the context notation
U_j	Context notation	23	combined utility for decision alternative j
U'_j	MCCD	52	Utility for decision alternative j, based on sum of logarithms
V_{FWD}	Routing traffic analysis	69	Validity function for route request forwarding
w_i	NWAUF, MCCD	46, 52	weight for criterion i
λ	C^2E^2S	48	sensor network density