Appendix

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A Proactive Environmental Monitoring Aware Routing

The Proactive variant of Environmental Monitoring Aware routing, Proactive EMA, which was introduced in [WPTGG08], shows that EMA routing can also be done proactively. As this routing protocol is referred to in different sections of this thesis, it is described in this appendix chapter.

Proactive EMA is a sink-initiated proactive routing protocol. In contrast to Reactive EMA, it is not that flexible but bound to the predefined set of context parameters, which are the *node health*, the *RSSI* (Received Signal Strength Indicator) and the *hop count*.

A.1 Route Update Signalling

Routing table creation and maintenance in Proactive EMA is based on beacons that are transmitted in the network. Each sink in the network triggers route updates by sending out periodic beacons. These *sink beacons* contain information about the sink's health and a hop count of 0. The content of the RSSI field, which is also present in the beacons, is undefined for sink beacons. A sensor node which receives a sink beacon (identified by the hop count value) determines the RSSI for this beacon and updates an internal *sink table* with the new information, including the measured RSSI value. Then it modifies the beacon by increasing the hop count by 1 and setting the health value to the lower of its own health and the health value from the received beacon. In this way, the beacon message always contains the lowest health value on the route. Additionally, the RSSI value is added to the beacon so that a quality indication of the path is available for the next nodes. After these changes, the beacon is rebroadcast.

The rebroadcast beacons (*neighbour beacons*) are then received by other nodes, of which some may not be in direct communication range of the sink. Upon receipt of a neighbour beacon, a node compares the current information about health, RSSI and hop count to the information it already has about the sending neighbour node and updates its internal *neighbour table* accordingly. If it did not have any information on that neighbour node yet, it creates a new neighbour table entry. Then it elects its best neighbour node. If there is a change related to the best neighbour, the beacon is rebroadcast with updated health, RSSI and hop count information. A "change related to the best neighbour" means that one of the following conditions is fulfilled:

- a new best neighbour is elected,
- a new beacon was received from the current best neighbour.

If there is no change related to the elected best neighbour, the neighbour beacon is not rebroadcast to save energy and to reduce network load. The rebroadcasting of each beacon from the best neighbour has two reasons: integration of new nodes and avoidance of route expiry. Integration of new nodes means that new sensor nodes which are joining the network can easily be integrated as beacons occur regularly. A route expiry can occur because either the topology changes or nodes fail. To avoid that the failure of a best neighbour remains undiscovered, a timeout is defined after which a neighbour table entry becomes invalid. The timeout has to be longer than the beacon interval so that it only occurs if there are no periodic beacons from the best neighbour any more. In the case of a timeout, a new best neighbour is elected.

A.2 Best Neighbour Election

Each node sorts both its neighbour table and its sink table according to a multiplicative utility function that has basically the same form as the *Multi-Criteria Context-based Decision function* (MCCD) that is introduced in chapter 4 of this thesis, with the only difference that all weights are set to 1:

$$U = \prod_{i=1}^{k} (f_{s,i}(c_i)) \tag{A.1}$$

where c_i is the value of the i-th context criterion and $f_{s,i}$ is a scaling function that maps c_i to the interval $[0,1]$. In the case of the neighbour table, the context criteria are the already mentioned criteria health, hop count and RSSI. For these criteria, the following settings were applied:

- **The health** is a parameter defined between 0 and 100. As good health is preferable, a linear downscaling, dividing by 100, can be used for this criterion.
- **The hop count** can be any non-negative integer value. As low hop counts are preferable, the scaling function should have its maximum for a hop count of 0 and be 0 for an infinite hop count. A negative exponential scaling function was chosen because it facilitates mapping of the possible hop count range $[0\ \infty]$ onto the interval $[0\ 1]$, with 0 hops being mapped onto 1.
- **The RSSI value** is given in dBW, and as long as the transmission power of the nodes is below 1 W (which is usually the case in wireless sensor networks), the RSSI always has a negative value. A high RSSI is preferable here. The scaling function chosen is a positive exponential function, which projects the value range $[-\infty\ 0]$ into the interval $[0\ 1]$. The exponent here has to be adapted to the usual value range of the RSSI in order to avoid that the RSSI criterion dominates the other two criteria.

The complete metric used here is

$$U = \frac{health}{100} * e^{-hopcount} * e^{\frac{RSSI}{50}}. \tag{A.2}$$

For sorting of the sink table, the hop count is not used, as it is always the same for a direct link to a sink. The health and RSSI are used in the same manner as for the neighbour table.

The best neighbour selection then works as follows:

- **If sinks are in communication range**, the best sink is elected as best neighbour node, thus using direct communication to the sink whenever this is possible.
- **If no sink is in communication range**, a neighbour node has to act as a multi-hop relay towards the sink. In this case, the best node from the neighbour table is elected.

A.3 Sensor Data Transmission

Whenever a sensor node has data to send, communication to the sink takes place on a hop-by-hop basis. The sending node looks up the current best neighbour node in the neighbour table and forwards its data to that node. The receiving node then does the same, and in this way the data packets travel through the network until they reach the destination. Acknowledgements are also transmitted according to this hop-by-hop forwarding: there are no end-to-end acknowledgements, but instead there are acknowledgements on each hop. This is sufficient for most sensor network scenarios where end-to-end acknowledged transmissions are not required. If an application relies on end-to-end acknowledgements, e.g. to fulfil QoS requirements, there has to be an additional end-to-end acknowledgement support, which could be provided by only acknowledging a transmission if the subsequent hop has been acknowledged. In this case, however, acknowledgement timeouts have to be dimensioned according to the expected maximum hop count in the sensor network.

B Decision Concept in [SRRWM08]

As the decision concept that was used for the results presented in [SRRWM08] is used to generate results for comparison in subsection 6.4.2, this concept is sketched here. It is an empirically chosen decision concept based on experiences of earlier simulations.

B.1 Goods Routing

The goods routing is kept simple here, the only decision criterion is the route length. 3 alternative routes are announced, each with a preference that is based on the route length. To be exact, the preference of route i is defined as

$$Pref_i = \frac{(1/routelength_i)^3}{\sum_{j=1}^{3}(1/routelength_j)^3} \tag{B.1}$$

where j is the index that represents the announced routes.

B.2 Vehicle Routing

The vehicle routing is more complex than the goods routing. The optimisation goal is the vehicle utilisation here. Based on the existing route announcements at the vertices, an estimated amount of available load is calculated. This estimate consists of two parts: The estimated amount of goods and the estimated available transport capacity, both calculated individually for each route hop.

The estimated amount of goods takes all goods route announcements into account that are present for a specific next hop, not equally weighted but according to their announced preference and the number of hops in the announced route:

$$N_{Goods,est,hop\_i} = \sum \left(Size * Pref * \frac{1}{hops+1} \right). \tag{B.2}$$

It has to be noted that the term $\frac{1}{hops+1}$ stands for the probability that the piece of good is really at the vertex when the vehicle arrives. For goods that are already present, this term is removed.

The estimated available transport capacity is similarly calculated but with a probability of decision change instead of a preference:

$$N_{Vehcap,est,hop\_i} = \sum \left(Capacity * Changeprob * \frac{1}{hops+1} \right). \tag{B.3}$$

For vehicles already present at the vertex, only the capacity is taken into account.

The estimated available load is then the difference between the available goods and the available transport capacity:

$$N_{Load,est,hop\_i} = N_{Goods,est,hop\_i} - NVehcap, est, hop\_i \tag{B.4}$$

The actual route decision is based on the available load on each route option, which is combined from the estimated available load at each of the hops. Additionally, routes that match those of goods which are currently on board and/or continue the current vehicle route get awarded a bonus. In this way, some stability of routes can be achieved. This is necessary because it was shown e.g. in [WPTG06] that too frequent route changes can lead to a reduced performance.

C Result Tables of Individual Logistic Simulation Runs

Table C.1: Individual results for table 6.3

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
1	10.6014	1.7010	0.7783	1.3560	2.0089	24295
	8.0834	2.1470	0.7882	1.3770	1.9261	24361
	7.2282	1.3500	0.7712	1.3468	1.9243	24553
	7.9003	1.8990	0.7715	1.3389	1.9426	24502
	7.8098	1.8680	0.7715	1.3358	1.9554	24434
	7.7280	1.9930	0.7626	1.3189	1.9016	24403
	8.4120	1.9890	0.7752	1.3346	1.9396	24445
	8.1054	1.5785	0.7654	1.3570	1.9923	24062
	7.3372	2.1500	0.7586	1.3173	1.8563	24557
	8.1436	2.3290	0.7673	1.3337	1.9077	24379
2	9.0160	1.8133	0.7762	1.3492	1.9693	24300
	8.1118	2.1700	0.7856	1.3608	1.9139	24331
	6.6724	1.5280	0.7563	1.3239	1.8976	24549
	7.9003	1.8990	0.7715	1.3389	1.9426	24502
	8.3628	2.0620	0.7749	1.3472	1.9804	24381
	7.6030	1.9188	0.7492	1.2926	1.9138	24403
	8.6341	2.0410	0.7751	1.3352	1.9439	24417
	8.1054	1.5785	0.7654	1.3570	1.9923	24062
	7.1060	2.1004	0.7612	1.3227	1.8600	24542
	8.1532	2.4000	0.7796	1.3824	2.0439	24403

Table C.1: Individual results for table 6.3 (continued)

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
3	8.8273	1.6855	0.7760	1.3476	1.9625	24346
	8.9522	2.3405	0.7878	1.3701	1.9461	24338
	6.6070	1.5420	0.7592	1.3258	1.9024	24567
	7.6515	1.7260	0.7703	1.3344	1.9370	24391
	8.3046	2.1028	0.7721	1.3459	1.9876	24334
	7.5806	1.9140	0.7485	1.2930	1.9102	24377
	8.7427	2.1220	0.7785	1.3500	1.9678	24357
	8.6607	1.7150	0.7627	1.3347	1.9992	24205
	7.1060	2.1004	0.7612	1.3227	1.8600	24542
	7.8393	2.1150	0.7642	1.3310	1.9567	24299
4	8.8273	1.6855	0.7760	1.3476	1.9625	24346
	8.7297	2.3890	0.7868	1.3663	1.9372	24388
	7.8010	1.5830	0.7816	1.3873	1.9818	24556
	7.4775	1.7780	0.7691	1.3357	1.9316	24321
	7.4032	1.9860	0.7693	1.3407	1.9340	24445
	7.5147	1.8190	0.7503	1.2909	1.9151	24426
	8.7452	2.1650	0.7748	1.3346	1.9639	24435
	8.6607	1.7150	0.7627	1.3347	1.9992	24205
	7.3254	2.0720	0.7604	1.3195	1.8767	24543
	8.2596	2.4110	0.7726	1.3764	2.0495	24225
5	9.6907	1.9480	0.7730	1.3631	2.0129	24042
	8.8520	2.5415	0.7907	1.3796	1.9263	24278
	7.8010	1.5830	0.7816	1.3873	1.9818	24556
	7.4775	1.7780	0.7691	1.3357	1.9316	24321
	7.4032	1.9860	0.7693	1.3407	1.9340	24445
	7.4828	1.8400	0.7498	1.2919	1.9191	24447
	8.7518	2.0630	0.7766	1.3405	1.9603	24427
	8.2193	1.7813	0.7592	1.3285	2.0009	24306
	7.1518	2.1417	0.7619	1.3254	1.8445	24604
	7.8632	2.4140	0.7678	1.3550	2.0284	24224

Table C.1: Individual results for table 6.3 (continued)

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
25	9.4460	2.0600	0.7785	1.3441	2.0287	24443
	8.7504	2.2060	0.7924	1.3649	1.9452	24277
	7.6015	1.4156	0.7721	1.3497	1.9364	24437
	7.4340	1.6380	0.7692	1.3321	1.9399	24504
	7.9481	2.0310	0.7713	1.3435	1.9708	24470
	7.4524	1.8660	0.7520	1.2957	1.9002	24490
	8.8122	2.0600	0.7828	1.3442	1.9774	24530
	8.1524	1.6230	0.7621	1.3304	2.0134	24256
	7.8510	2.3100	0.7593	1.3223	1.8804	24566
	7.9795	2.4685	0.7679	1.3758	1.9837	24328
100	9.4355	2.2480	0.7786	1.3541	2.0390	24237
	8.8468	2.5620	0.7999	1.3852	1.9354	24273
	7.5977	1.4290	0.7694	1.3079	1.9344	24600
	8.3772	1.9390	0.7649	1.3283	1.9635	24335
	7.3644	2.0230	0.7757	1.3480	1.9459	24359
	7.9468	1.9634	0.7538	1.2936	1.9125	24459
	8.0011	1.9290	0.7704	1.3106	1.9154	24525
	8.7539	1.8505	0.7615	1.3389	2.0123	24332
	8.0037	2.3400	0.7647	1.3329	1.9070	24467
	8.1168	2.4070	0.7714	1.3717	2.0281	24305
500	8.9619	2.0370	0.7814	1.3512	1.9870	24394
	8.4647	2.1200	0.7990	1.3924	1.9310	24287
	6.8431	1.0450	0.7617	1.3212	1.9195	24635
	8.5825	2.1010	0.7721	1.3481	1.9775	24457
	7.8294	2.0039	0.7719	1.3460	1.9817	24310
	8.0265	2.0115	0.7672	1.3301	1.9241	24404
	8.5219	2.4395	0.7809	1.3396	1.9113	24384
	8.5587	1.8510	0.7603	1.3354	2.0468	24311
	7.3733	2.5270	0.7572	1.3062	1.8509	24561
	8.2077	2.6180	0.7685	1.3722	1.9995	24372

Table C.2: Individual results for table 6.4

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
1;2	10.6014	1.7010	0.7783	1.3560	2.0089	24295
5;25	8.0834	2.1470	0.7882	1.3770	1.9261	24361
	7.2282	1.3500	0.7712	1.3468	1.9243	24553
	7.9003	1.8990	0.7715	1.3389	1.9426	24502
	7.8098	1.8680	0.7715	1.3358	1.9554	24434
	7.7280	1.9930	0.7626	1.3189	1.9016	24403
	8.4120	1.9890	0.7752	1.3346	1.9396	24445
	8.1054	1.5785	0.7654	1.3570	1.9923	24062
	7.3372	2.1500	0.7586	1.3173	1.8563	24557
	8.1436	2.3290	0.7673	1.3337	1.9077	24379
100	9.4319	2.0330	0.7787	1.3625	2.0372	24184
	9.6351	1.8155	0.7777	1.3386	1.9966	24166
	6.5328	1.2537	0.7623	1.3371	1.9643	24570
	7.8994	1.4680	0.7856	1.3712	2.0413	24199
	8.2318	1.7941	0.7740	1.3555	2.0271	24485
	7.1045	1.7160	0.7616	1.3216	1.9002	24419
	9.1974	1.7830	0.7651	1.3029	1.9482	24490
	7.2729	1.5480	0.7509	1.3145	1.9367	24373
	7.4994	1.8930	0.7481	1.3080	1.8650	24525
	8.0458	2.2291	0.7616	1.3320	1.9748	24339
250	9.0565	1.0425	0.7740	1.3676	2.0184	23866
	8.6641	1.7235	0.7693	1.3533	2.0146	24244
	7.3432	1.8610	0.7669	1.3396	1.9688	24403
	8.5463	1.7230	0.7723	1.3498	1.9922	24351
	7.8118	1.9830	0.7717	1.3515	1.9830	24470
	8.5205	2.0760	0.7736	1.3753	1.9961	24385
	7.3279	1.2635	0.7592	1.3033	1.9259	24384
	7.8774	1.5005	0.7605	1.3557	1.9788	24332
	6.8629	2.0160	0.7459	1.2853	1.8446	24566
	7.7085	1.8655	0.7733	1.3887	2.0150	24460

Table C.2: Individual results for table 6.4 (continued)

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
500	6.6073	0.6990	0.7672	1.3221	1.9324	24533
	7.1922	1.1811	0.7674	1.3466	1.9479	24430
	5.8123	0.6830	0.7327	1.2917	1.9076	24548
	7.0233	0.8923	0.7522	1.3397	1.9484	24508
	5.7242	0.4000	0.7571	1.3055	1.9348	24491
	6.7343	0.2896	0.7582	1.3098	1.9685	24516
	5.9372	1.0400	0.7246	1.2594	1.8677	24547
	6.3242	0.6500	0.7383	1.2881	1.8998	24555
	6.3220	0.7074	0.7328	1.2445	1.8443	24558
	8.0423	1.1990	0.7553	1.3203	1.9644	24393
750	5.2081	-0.2080	0.7274	1.2666	1.8882	24073
	4.5215	-0.6640	0.7103	1.2451	1.8643	24114
	4.7809	0.1380	0.7083	1.2277	1.8636	24272
	4.7932	0.0595	0.7092	1.2315	1.8182	24226
	4.8385	0.3640	0.7217	1.2474	1.8324	24291
	5.1932	0.4575	0.7313	1.2645	1.8515	24290
	5.0387	0.2900	0.7342	1.2815	1.8419	24098
	5.6845	0.7320	0.7209	1.2502	1.8419	24182
	5.8318	0.7285	0.7296	1.2576	1.8514	24298
	5.1914	0.2190	0.7353	1.2742	1.8704	24163
990	3.7463	0.0700	0.7157	1.2058	1.7693	23745
	4.8096	0.6100	0.7030	1.2019	1.8190	23296
	3.7971	0.0655	0.6807	1.1745	1.7626	23580
	4.0800	-0.1335	0.6916	1.1792	1.7654	23710
	3.4730	-0.0020	0.7169	1.2256	1.7386	23451
	4.2303	0.2770	0.7034	1.2069	1.7618	23679
	4.9957	0.7030	0.7159	1.2559	1.8382	22940
	4.1974	0.2230	0.7023	1.2225	1.7936	23409
	3.4144	-0.2720	0.6814	1.1656	1.7180	23687
	4.7546	0.3595	0.6920	1.2016	1.7878	23084

Table C.3: Individual results for table 6.5

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
1	-1.1157	-7.7860	0.7827	1.3499	1.8568	23955
	-1.6573	-6.9790	0.7732	1.3312	1.7852	24201
	-0.6032	-6.3400	0.7929	1.3801	1.8503	24261
	-1.0526	-6.9630	0.7758	1.3483	1.8755	24014
	-2.2351	-6.8000	0.7779	1.3368	1.7883	24491
	-1.1887	-7.0450	0.8010	1.3821	1.8570	24379
	-1.1634	-6.8960	0.7751	1.3317	1.8066	24411
	-1.0991	-6.5787	0.7821	1.3645	1.8564	24366
	-1.3523	-6.3230	0.7783	1.3317	1.7834	24468
	-0.0405	-6.2150	0.7969	1.3825	1.8505	24321
2	0.2911	-7.8740	0.7786	1.3466	1.8732	23738
	-1.1846	-7.1870	0.7767	1.3445	1.8099	24211
	-0.3389	-6.4930	0.7939	1.3762	1.8637	24277
	-0.7472	-6.7983	0.7784	1.3370	1.8702	24264
	-2.2836	-6.8470	0.7823	1.3437	1.8029	24518
	-1.2101	-7.1000	0.7996	1.3831	1.8454	24379
	-0.7111	-6.9120	0.7774	1.3400	1.8215	24333
	-1.0991	-6.5787	0.7821	1.3645	1.8564	24366
	-0.6693	-6.2720	0.7777	1.3321	1.7988	24537
	-1.2042	-6.2844	0.7895	1.3648	1.7938	24456
3	-0.0370	-7.7860	0.7786	1.3461	1.8765	23821
	-0.4095	-6.8192	0.7749	1.3385	1.8145	23956
	-0.6774	-6.7410	0.7743	1.3462	1.8219	24278
	-0.7091	-6.9140	0.7773	1.3443	1.8761	24122
	-2.4212	-6.8420	0.7833	1.3448	1.8014	24513
	-1.2554	-6.7010	0.7937	1.3783	1.8025	24215
	-0.4918	-6.9510	0.7727	1.3383	1.8219	24106
	-1.0333	-6.7332	0.7791	1.3641	1.8408	24342
	-1.0751	-6.3155	0.7832	1.3329	1.7901	24508
	-1.0753	-6.4560	0.7851	1.3664	1.7965	24205

Table C.3: Individual results for table 6.5 (continued)

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
4	0.0287	-7.8800	0.7791	1.3447	1.8779	23848
	-1.0871	-7.0100	0.7749	1.3436	1.8192	24135
	-0.6774	-6.7410	0.7743	1.3462	1.8218	24278
	-0.7091	-6.9140	0.7773	1.3443	1.8761	24122
	-2.0633	-6.9980	0.7779	1.3336	1.8066	24463
	-0.6842	-6.6280	0.7949	1.3710	1.8537	24334
	-0.7613	-6.5305	0.7811	1.3328	1.8061	24410
	-1.5025	-6.6885	0.7827	1.3666	1.8406	24432
	-1.8268	-6.3990	0.7718	1.3058	1.7353	24511
	-1.0676	-6.3020	0.7867	1.3556	1.7870	24373
5	-1.2761	-7.3345	0.7688	1.3129	1.8117	24042
	-1.3143	-7.2331	0.7799	1.3363	1.8022	24223
	-1.4914	-6.8660	0.7757	1.3411	1.8018	24480
	-0.3867	-7.1300	0.7729	1.3298	1.8915	24144
	-1.8256	-6.8360	0.7785	1.3339	1.8156	24532
	-1.3968	-6.8835	0.7935	1.3571	1.8047	24342
	-0.7613	-6.5305	0.7811	1.3328	1.8061	24410
	-1.5025	-6.6885	0.7827	1.3666	1.8406	24432
	-1.0257	-6.3130	0.7754	1.3032	1.7759	24521
	-1.3264	-6.3077	0.7872	1.3604	1.7829	24477
25	0.2853	-7.4380	0.7811	1.3290	1.9021	24179
	-1.0632	-6.9590	0.7745	1.3351	1.7907	24177
	-1.7087	-6.6035	0.7667	1.3256	1.8024	24516
	-0.7505	-7.0430	0.7806	1.3517	1.8709	24237
	-2.2159	-6.9970	0.7838	1.3464	1.7943	24517
	-1.8920	-6.9010	0.7958	1.3658	1.7938	24326
	-0.2610	-7.0300	0.7675	1.3401	1.8275	23885
	-1.1537	-6.7650	0.7760	1.3465	1.8519	24339
	-1.3768	-6.5110	0.7646	1.3013	1.7693	24534
	-0.9851	-6.4140	0.7900	1.3663	1.8236	24359

Table C.3: Individual results for table 6.5 (continued)

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
100	-1.1157	-7.4040	0.7720	1.3155	1.8170	24383
	-1.4068	-7.0090	0.7802	1.3387	1.7831	24139
	-0.9622	-6.5180	0.7845	1.3500	1.8257	24476
	-1.7396	-7.2810	0.7772	1.3402	1.8011	24519
	-1.9345	-6.7660	0.7777	1.3321	1.7964	24413
	-0.9634	-6.6180	0.7942	1.3661	1.8160	24346
	-0.1940	-6.8885	0.7759	1.3387	1.8580	24068
	-1.3251	-6.7310	0.7758	1.3515	1.8289	24388
	-1.3529	-6.2030	0.7738	1.3125	1.7778	24513
	-1.6428	-6.4650	0.7854	1.3628	1.7990	24427
500	-1.7010	-7.4800	0.7692	1.3112	1.7966	24411
	-1.0356	-6.6365	0.7842	1.3501	1.8043	24290
	-0.7587	-6.2610	0.7905	1.3694	1.8282	24399
	-1.3876	-7.1653	0.7730	1.3369	1.8003	24427
	-1.0632	-6.3330	0.7893	1.3561	1.8481	24441
	-0.8615	-6.6910	0.7942	1.3720	1.8411	24304
	-0.8907	-6.9340	0.7680	1.3458	1.8260	23801
	-1.1625	-6.6520	0.7792	1.3620	1.8657	24362
	-1.7955	-6.5780	0.7614	1.2989	1.7792	24443
	-1.6354	-6.3400	0.7815	1.3533	1.7707	24443

Table C.4: Individual results for table 6.6

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
1;25	-1.1157	-7.7860	0.7827	1.3499	1.8568	23955
	-1.6573	-6.9790	0.7732	1.3312	1.7852	24201
	-0.6032	-6.3400	0.7929	1.3801	1.8503	24261
	-1.0526	-6.9630	0.7758	1.3483	1.8755	24014
	-2.2351	-6.8000	0.7779	1.3368	1.7883	24491
	-1.1887	-7.0450	0.8010	1.3821	1.8570	24379
	-1.1634	-6.8960	0.7751	1.3317	1.8066	24411
	-1.0991	-6.5787	0.7821	1.3645	1.8564	24366
	-1.3523	-6.3230	0.7783	1.3317	1.7834	24468
	-0.0405	-6.2150	0.7969	1.3825	1.8505	24321
100	-1.2737	-7.2600	0.7723	1.3160	1.8066	24289
	-0.3070	-6.1635	0.7988	1.3713	1.8361	24124
	-0.7894	-6.5160	0.7801	1.3395	1.8273	24219
	0.6521	-6.9181	0.7907	1.4126	1.8811	23730
	-1.1228	-6.6110	0.7930	1.3729	1.8500	24315
	-0.9525	-6.5550	0.7814	1.3440	1.8288	24443
	-0.1079	-7.0070	0.7629	1.3043	1.8194	24420
	-1.4633	-6.6070	0.7899	1.3782	1.8128	24478
	-1.5662	-6.4355	0.7761	1.3265	1.7849	24542
	-0.6106	-6.4100	0.7917	1.3608	1.8077	24318
250	0.2101	-7.1975	0.7963	1.3456	1.8246	24566
	-1.8802	-6.6130	0.7796	1.3521	1.7608	24440
	-1.8637	-6.4064	0.7671	1.3232	1.7702	24579
	-2.3731	-6.9780	0.7796	1.3237	1.7637	24471
	-1.7875	-6.9815	0.7742	1.3398	1.8176	24412
	-0.4803	-6.6655	0.8039	1.4254	1.8865	24264
	-1.0400	-7.1950	0.7763	1.3386	1.8436	24375
	-1.3857	-6.7460	0.7874	1.3631	1.7800	24459
	-1.8376	-6.7505	0.7617	1.3050	1.7618	24570
	-2.2345	-6.7620	0.7739	1.3370	1.7562	24449

Table C.4: Individual results for table 6.6 (continued)

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
500	-2.2650	-8.1034	0.7664	1.3527	1.7737	24444
	-2.8104	-7.9840	0.7557	1.3228	1.7504	24285
	-3.5458	-8.4535	0.7455	1.3024	1.7242	24566
	-2.3261	-7.9620	0.7810	1.3675	1.7878	24417
	-3.6854	-8.2160	0.7613	1.3122	1.7224	24423
	-2.3348	-8.2450	0.7812	1.3642	1.7935	24234
	-3.3466	-7.9710	0.7619	1.3228	1.7019	24483
	-4.0400	-8.0370	0.7408	1.2707	1.6704	24577
	-4.0666	-8.0790	0.7426	1.2635	1.6802	24577
	-3.8489	-7.9970	0.7558	1.3092	1.7031	24453
750	-4.8547	-8.5950	0.7433	1.2782	1.6319	24315
	-4.9815	-9.0135	0.7465	1.2913	1.6060	24174
	-5.6148	-9.0230	0.7114	1.2318	1.5868	24335
	-5.0643	-9.1810	0.7358	1.2740	1.6331	24299
	-4.8171	-8.8480	0.7346	1.2520	1.6303	24311
	-4.4278	-8.4165	0.7479	1.2978	1.6419	24292
	-4.9647	-8.6500	0.7386	1.2808	1.5903	24226
	-4.7361	-8.6950	0.7303	1.2671	1.6281	24191
	-4.3936	-8.6200	0.7322	1.2609	1.6244	24184
	-5.0229	-8.5900	0.7282	1.2543	1.6218	24258
1000	-6.3904	-9.2320	0.7153	1.1991	1.5224	23759
	-6.1789	-9.0970	0.6978	1.1756	1.5117	23707
	-6.9739	-9.6028	0.6982	1.2023	1.4754	23790
	-6.4172	-9.6210	0.6918	1.1788	1.4683	23767
	-6.2289	-9.1920	0.7076	1.2132	1.4759	23461
	-6.1968	-9.2305	0.6837	1.1688	1.4641	23538
	-6.0829	-9.0990	0.7114	1.2138	1.4981	23668
	-6.5907	-9.7840	0.6823	1.1822	1.4627	23397
	-6.4290	-9.4060	0.6907	1.1779	1.4738	23712
	-6.3395	-8.9320	0.7090	1.2312	1.4919	23244

Table C.4: Individual results for table 6.6 (continued)

Weight	Mean delay	Median delay	Capacity utilisation	Average rel. distance	Package cost (mu/km)	Delivered packages
1500	-8.5337	-10.2950	0.5551	1.1200	1.2339	18879
	-8.5768	-10.4080	0.5560	1.1243	1.2595	19155
	-8.0569	-9.9700	0.5592	1.1458	1.3017	18296
	-8.7568	-10.5720	0.5499	1.0955	1.2398	19403
	-7.9390	-9.8620	0.5499	1.1060	1.2950	18990
	-8.0398	-9.9485	0.5729	1.1225	1.2731	19646
	-8.7544	-10.4280	0.5594	1.1040	1.2658	19343
	-8.6601	-10.3595	0.5534	1.1287	1.2468	18950
	-8.5793	-10.3829	0.5612	1.1304	1.2747	19088
	-8.4109	-9.9170	0.5663	1.1184	1.2731	19369

D DLRP Message Sizes

Although the actual sizes of DLRP messages are dependent on implementation details and decisions about how detailed the carried information should be, rough estimations are done here to be able to discuss traffic volumes that are created by DLRP. The estimations are based on the minimal set of information that needs to be included. Furthermore, the following assumptions are made:

- addresses of logistic entities are 32-bit integers
- MCCD is used for the route decisions
- 3 context criteria are used in the decisions
- 3 scaling parameters are required per scaling function

Because of these assumptions, the calculated message sizes have to be regarded as examples. If more criteria or more complex scalings are used, the messages can grow larger.

D.1 Route Request Messages

In 3.3.3.1, it was already mentioned what the DLRP messages need to contain. This is now listed here in detail with sizes that are likely for the fields.

- vehicle/package flag (boolean, 1 bit)
- message type (2 bits)
- sender address (integer, 32 bit)
- destination address (integer, 32 bit)
- sequence number (short integer, 8 bit)
- time to live (short integer, 8 bit)
- due time (integer timestamp, 32 bit)
- size or capacity (floating point, 32 bit)
- hop list with multiple elements that consist of
  - hop address (integer, 32 bit)
  - expected arrival time (integer timestamp, 32 bit)
  - expected leave time (integer timestamp, 32 bit)
- context field with the following contents
  - context criteria identifier (3x 8 bit $\rightarrow$ 24 bit)
  - scaling type identifiers (3x 8 bit $\rightarrow$ 24 bit)

  - scaling parameters (9x floating point, 32 bit → 288 bit)
  - context weights (3x floating point, 32 bit → 96 bit)
  - context limits (4x floating point, 32 bit → 128 bit)
  - context values (3x floating point, 32 bit → 96 bit)

When these numbers are summed up, the resulting message size is $803 + n * 96$ bit, where n is the number of hops. Padding can be applied to create complete octets. Including the padding, the message size is $101 + n * 12$ Byte. Of course, this is the size at application level, and lower layer protocol (e.g. TCP/IP) overhead is not included.

D.2 Route Reply Messages

In implementations where the destination just copies the route request to a route reply, the message size remains the same, only the content of the message type field is changed, the time to live field is replaced by a hop count field and source and destination may be swapped. However, it can be assumed that the vehicle or package remembers with which parameters it has initiated the route discovery, so that the context field may be significantly reduced. If the route reply is cut down to the absolutely necessary information, the following contents remain:

- message type (2 bits)
- sender address (integer, 32 bit)
- destination address (integer, 32 bit)
- sequence number (short integer, 8 bit)
- hop count (short integer, 8 bit)
- hop list with multiple elements that consist of
  - hop address (integer, 32 bit)
  - expected arrival time (integer timestamp, 32 bit)
  - expected leave time (integer timestamp, 32 bit)
- context field with the following contents
  - context values (3x floating point, 32 bit → 96 bit)

In this case, the resulting message size is $178 + n * 96$ bit, or (with padding) $23 + n * 12$ Byte.

D.3 Route Announcement Messages

The route announcements inform a vertex about the planned arrival and departure of a vehicle or packet. For this, it has to contain at least the following fields:

- vehicle/package flag (boolean, 1 bit)
- message type (2 bits)
- sender address (integer, 32 bit)
- announcement number (short integer, 8 bit)
- expected arrival time (integer timestamp, 32 bit)
- expected leave time (integer timestamp, 32 bit)
- next hop address (integer, 32 bit)
- size or capacity (floating point, 32 bit)
- route preference (floating point, 32 bit)

The sum of these fields results in 203 bit, which, assuming the use of padding, corresponds to 26 Byte.

D.4 Route Disannouncement Messages

A route disannouncement needs to refer to a previous announcement, so it has to contain enough data to uniquely identify the announcement that has to be cancelled.

- vehicle/package flag (boolean, 1 bit)
- message type (2 bits)
- sender address (integer, 32 bit)
- announcement number (short integer, 8 bit)
- next hop address (integer, 32 bit)

This results in 75 bit, if padding is used to have complete octets, the disannouncement size is 10 Byte.

Bibliography

[AKK04] J.N. Al-Karaki and A.E. Kamal. Routing techniques in wireless sensor networks: a survey. *IEEE Wireless Communications*, 11(6):6–28, December 2004.

[BB04] J. Berger and M. Barkaoui. A parallel hybrid genetic algorithm for the vehicle routing problem with time windows. *Computers & Operations Research*, 31(12):2037–2053, October 2004.

[BC03] S. Bandyopadhyay and E.J. Coyle. An energy efficient hierarchical clustering algorithm for wireless sensor networks. In *Proc. 22nd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM)*, volume 2, pages 1713–1723, April 2003.

[Bec04] D. Beckett. Rdf/xml syntax specification (revised). W3C Recommendation (http://www.w3.org/TR/rdf-syntax-grammar/), February 2004.

[BWG05] M. Becker, B.-L. Wenning, and C. Görg. Integrated simulation of communication networks and logistical networks - using object-oriented programming language features to enhance modelling. In A.N. Ince and E. Topuz, editors, *Modeling and Simulation Tools for Emerging Telecommunication Networks: Needs, Trends, Challenges and Solutions*, pages 279–287. Springer, 2005.

[BWG+06] M. Becker, B.-L. Wenning, C. Görg, J.D. Gehrke, M. Lorenz, and O. Herzog. Agent-based and discrete event simulation of autonomous logistic process. In W. Borutzky, A. Orsoni, and R. Zobel, editors, *Proc. 20th European Conference on Modelling and Simulation*, pages 566–571, May 2006.

[BWLG07] M. Becker, T.L. Weerawardane, X. Li, and C. Görg. Extending opnet modeler with external pseudo random number generators and statistical evaluation by the limited relative error algorithm. In N. Ince and A. Bragg, editors, *Recent Advances in Modeling and Simulation Tools for Communication Networks and Services*, pages 241–255. Springer, 2007.

[Cis00] *Internetworking Technology Handbook*, chapter 39. Cisco Press, 3rd edition, 2000.

[CJ03] T. Clausen and P. Jacquet. Optimized link state routing protocol (olsr). IETF RFC 3626, October 2003.

[Com08] Communication Networks, University of Bremen. *CNCL Documentation*, 2008. http://www.comnets.uni-bremen.de/docs/cncl/index.html.

Bernd-Ludwig Wenning, *Context-Based Routing in Dynamic Networks*,
DOI 10.1007/978-3-8348-9709-1,

[Com09] Communication Networks, University of Bremen. *LoCoSim Documentation*, 2009. http://www.comnets.uni-bremen.de/docs/locosim/index.html.

[CP07] I. Chakeres and C. Perkins. Dynamic manet on-demand (dymo) routing. IETF draft: draft-ietf-manet-dymo-08, March 2007.

[DA99] A.K. Dey and G.D. Abowd. Towards a better understanding of context and context-awareness. In *1st International Symposium on Handheld and Ubiquitous Computing (HUC)*, pages 304–307, June 1999.

[Dij59] E.W. Dijkstra. A note on two problems in connexion with graphs. *Numerische Mathematik*, 1(1):269–271, December 1959.

[DR59] G.B. Dantzig and J.H. Ramser. The truck dispatching problem. *Management Science*, 6(1):80–91, October 1959.

[Haa97] Z.J. Haas. A new routing protocol for the reconfigurable wireless networks. In *Proc. 6th IEEE International Conference on Universal Personal Communications, IEEE ICUPC'97*, volume 2, pages 562–566, October 1997.

[HCB00] W.R. Heinzelman, A. Chandrakasan, and H. Balakrishnan. Energy-efficient communication protocol for wireless microsensor networks. In *Proc. 33rd Annual Hawaii International Conference onSystem Sciences*, volume 2, pages 1–10, January 2000.

[HH06] T.T. Huynh and C.S. Hong. An energy*delay efficient multi-hop routing scheme for wireless sensor networks. *IEICE Transactions on Inf. & Syst.*, E89-D(5):1654–1661, May 2006.

[HKB99] W.R. Heinzelman, J. Kulik, and H. Balakrishnan. Adaptive protocols for information dissemination in wireless sensor networks. In *Proc. 5th annual International Conference on Mobile Computing and Networking(MOBICOM)*, pages 174–185, 1999.

[IEE03] IEEE. *IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)*, 2003. Revised 2006.

[IGE00] C. Intanagonwiwat, R. Govindan, and D. Estrin. Directed diffusion: a scalable and robust communication paradigm for sensor networks. In *Proc. 6th annual International Conference on Mobile Computing and Networking (MOBICOM)*, pages 56–67, 2000.

[Jaf84] J.M. Jaffe. Algorithms for finding paths with multiple constraints. *Networks*, 14(1):95–116, 1984.

[JM96] D. Johnson and D. Maltz. Dynamic source routing in ad hoc wireless networks. In T. Imielinski and H. Korth, editors, *Mobile Computing*, pages 153–181. 1996.

[KHB02] J. Kulik, W.R. Heinzelman, and H. Balakrishnan. Negotiation-based protocols for disseminating information in wireless sensor networks. *Wireless Networks*, 8:169–185, 2002.

[LBA+05] Q. Li, J. Beaver, A. Amer, P.K. Chrysanthis, A. Labrinidis, and G. Santhankrishnan. Multi-criteria routing in wireless sensor-based pervasive environments. *Journal of Pervasive Computing and Communications*, 1(4):313–326, December 2005.

[LR02] S. Lindsey and C.S. Raghavendra. Pegasis: Power efficient gathering in sensor information systems. In *Proc. IEEE Aerospace Conference*, volume 3, pages 3–1125 – 3–1130, March 2002.

[LR05] Q. Liang and Q. Ren. Energy and mobility aware geographical multipath routing for wireless sensor networks. In *Proc. IEEE Wireless Communications and Networking Conference 2005*, pages 1867–1871, March 2005.

[Luk07] A. Lukosius. Opportunistic routing in multi-sink mobile ad hoc wireless sensor networks. Master's thesis, Communication Networks, University of Bremen, 2007.

[MA01] A. Manjeshwar and D.P. Agrawal. Teen: a routing protocol for enhanced efficiency in wireless sensor networks. In *Proc. 15th International Parallel and Distributed Processing Symposium*, pages 2009–2015, April 2001.

[MA02] A. Manjeshwar and D.P. Agrawal. Apteen: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks. In *Proc. International Parallel and Distributed Processing Symposium 2002*, pages 195–202, April 2002.

[Mal98] G. Malkin. Rip version 2. IETF RFC 2453, November 1998.

[McC87] J. McCarthy. Generality in artificial intelligence. *Communications of the ACM*, 30(12):1030–1035, December 1987.

[McC93] J. McCarthy. Notes on formalizing context. In *Proc. 13th International Joint Conference on Artificial Intelligence*, pages 555–560, 1993.

[MHM05] M. Musolesi, S. Hailes, and C. Mascolo. Adaptive routing for intermittently connected mobile ad hoc networks. In *Proc. 6th IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks (WoWMoM) 2005*, pages 183–189, 2005.

[MM98] S. Mitrovic-Minic. Pickup and delivery problems: A survey. Technical report, Simon Fraser University, May 1998.

[MM06] C. Mascolo and M. Musolesi. Scar: Context-aware adaptive routing in delay tolerant mobile sensor networks. In *Proc. 2006 International Conference on Wireless Communications and Mobile Computing*, pages 533–538, 2006.

[Moy98] J. Moy. Ospf version 2. IETF RFC 2328, April 1998.

[MTT+06] B. Malakooti, I. Thomas, S.K. Tanguturi, S. Gajurel, H. Kim, and K. Bhasin. Multiple criteria network routing with simulation results. In *Proc. 15th Industrial Engineering Research Conference (IERC)*, May 2006.

[MvH04] D.L. McGuinness and F. van Harmelen. Owl ontology web language overview. W3C Recommendation (http://www.w3.org/TR/owl.features/), February 2004.

[Nat98] United Nations. Kyoto protocol to the united nations framework convention on climate change. http://unfccc.int/resource/docs/convkp/kpeng.pdf, 1998.

[NB00] W.P. Nanry and J.W. Barnes. Solving the pickup and delivery problem with time windows using reactive tabu search. *Transportation Research Part B*, 34(2):107–121, February 2000.

[OPN08] OPNET. Opnet modeler. Web page: http://opnet.com/solutions/network_rd /modeler.html, 2008.

[otEC04] Commission of the European Communities. Communication from the commission to the council and the european parliament - implementing the community strategy to reduce co2 emissions from cars: - fourth annual report on the effectiveness of the strategy (reporting year 2002). Web resource: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2004:0078:FIN:EN:PDF, 2004.

[OZ08] Open-ZB. Open-source toolset for ieee 802.15.4 and zigbee. Web page: http://open-zb.net, 2008.

[PB94] C. Perkins and P. Bhagwat. Highly dynamic destination-sequenced distance-vector routing (dsdv) for mobile computers. In *Proc. ACM SIGCOMM'94 Conference on Communications Architectures, Protocols and Applications*, pages 234–244, 1994.

[PBRD03] C. Perkins, E. Belding-Royer, and S. Das. Ad hoc on-demand distance vector (aodv) routing. IETF RFC 3561, July 2003.

[PMGB02] W.B. Powell, A. Marar, J. Gelfand, and S. Bowers. Implementing real-time optimization models: A case application from the motor carrier industry. *Operations Research*, 50(4):571–581, 2002.

[PMM07] B. Pasztor, M. Musolesi, and C. Mascolo. Opportunistic mobile sensor data collection with scar. In *Proc. IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS) 2007*, pages 1–12, October 2007.

[Psa88] H.N. Psaraftis. Dynamic vehicle routing problems. In B.L. Golden and A.A. Assad, editors, *Vehicle Routing: Methods and Studies*, pages 223–248. North-Holland, Amsterdam, 1988.

[Rea06] S. Rea. *Dynamic route management strategies for mobile ad-hoc networks*. PhD thesis, Centre for Adaptive Wireless Systems, Cork Institute of Technology, 2006.

[RLH06] Y. Rekhter, T. Li, and S. Hares. A border gateway protocol 4 (bgp-4). IETF RFC 4271, January 2006.

[RMSM01] E.M. Royer, P.M. Melliar-Smith, and L.E. Moser. An analysis of the optimum node density for ad hoc mobile networks. In *IEEE International Conference on Communications (ICC) 2001*, volume 3, pages 857–861, 2001.

[RMSR09] H. Rekersbrink, T. Makuschwitz, and B. Scholz-Reiter. A distributed routing concept for vehicle routing problems. *Logistics Research*, 1(1):45–52, 2009.

[SAW+04] B.J. Stocks, M.E. Alexander, B.M. Wotton, C.N. Stefner, M.D. Flannigan, S.W. Taylor, N. Lavoie, J.A. Mason, G.R. Hartley, M.E. Maffey, G.N. Dalrymple, T.W. Blake, M.G. Cruz, and R.A. Lanoville. Crown fire behaviour in a northern jack pine - black spruce forest. *Canadian Journal of Forest Research*, 34(8):1548–1560, 2004.

[Sch04] J. Schönberger. *Operational Freight Carrier Planning - Investigations on Basic Concepts, Optimization Models and Advanced Memetic Algorithms*. PhD thesis, Chair for Logistics, University of Bremen, 2004.

[Sch05] A. Schrijver. On the history of combinatorial optimization (till 1960). In K. Aardal, G.L. Nemhauser, and R. Weismantel, editors, *Handbook of Discrete Optimization*, pages 1–68. Elsevier, Amsterdam, 2005.

[SF06] R. Subramanian and F. Fekri. Sleep scheduling and lifetime maximization in sensor networks: fundamental limits and optimal solutions. In *Proc. 5th international conference on Information processing in sensor networks*, pages 218–225, 2006.

[SLPF03] T. Strang, C. Linnhoff-Popien, and K. Frank. Cool: A context ontology language to enable contextual interoperability. In J.-B. Stefani, I. Dameure, and D. Hagimont, editors, *LNCS 2893: Proc. 4th IFIP WG 6.1 International Conference on Distributed Applications and Interoperable Systems (DAIS2003)*, volume 2893 of *Lecture Notes in Computer Science (LNCS)*, pages 236–247, November 2003.

[Sol87] M.M. Solomon. Algorithms for the vehicle routing and scheduling problems with time window constraints. *Operations Research*, 35(2):254–265, 1987.

[SRFR+05] B. Scholz-Reiter, M. Freitag, H. Rekersbrink, B.-L. Wenning, C. Gorldt, and W. Echelmeyer. Auf dem weg zur selbststeuerung in der logistik - grundlagenforschung und praxisprojekte. In G. Wäscher, K. Inderfurth, G. Neumann, M. Schenk, and D. Ziems, editors, *Intelligente Logistikprozesse - Konzepte, Lösungen, Erfahrungen.Begleitband zur 11. Magdeburger Logistiktagung*, pages 166–180, 2005.

[SRRF06] B. Scholz-Reiter, H. Rekersbrink, and M. Freitag. Internet routing protocols as an autonomous control approach for transport networks. In R. Teti, editor, *Proc. 5th CIRP international seminar on intelligent computation in manufacturing engineering*, pages 341–345, 2006.

[SRRWM08] B. Scholz-Reiter, H. Rekersbrink, B.-L. Wenning, and T. Makuschewitz. A survey of autonomous control algorithms by means of adapted vehicle routing problems. In *Proc. 9th Biennal ASME Conference on EngineeringSystems Design and Analysis (ESDA 08)*, pages CD–ROM, 6 pages, July 2008.

[SRWF04] B. Scholz-Reiter, K. Windt, and M. Freitag. Autonomous logistic processes: New demands and first approaches. In L. Monostori, editor, *Proc. 37th CIRP international Seminar on Manufacturing Systems*, pages 357–362, 2004.

[ST66] M.D. Springer and W.E. Thompson. The distribution of products of independent random variables. *SIAM Journal on Applied Mathematics*, 14(3):511–526, May 1966.

[SW65] S.S. Shapiro and M.B. Wilk. An analysis of variance test for normality (complete samples). *Biometrika*, 52(3 and 4):591–611, 1965.

[Tex07] Texas Instruments. *CC2420 2.4 GHz IEEE 802.15.4/ZigBee-ready RF transceiver (Rev. B)*, March 2007.

[Tho06] I.J. Thomas. Design, analysis and simulation of a distributed multiple criteria network routing method. Master's thesis, Department of Electrical Engineering and Computer Science, Case Western Reserve University, Cleveland, Ohio, USA, 2006.

[Tin] Tinyaodv implementation. TinyOS source code repository: http://tinyos.cvs.sourceforge.net/viewvc/tinyos/tinyos-1.x/contrib/hsn/.

[Tin08] Tinyos community forum. Web page: http://www.tinyos.net, 2008.

[WBP05] K. Windt, F. Böse, and T. Philipp. Criteria and application of autonomous cooperating logistic processes. In J.X. Gao, D.I. Baxter, and P.J. Sackett, editors, *Proc. 3rd International Conference on Manufacturing Research . Advances in Manufacturing Technology and Management*, 2005.

[WGP05] B.-L. Wenning, C. Görg, and K. Peters. Ereignisdiskrete modellierung von selbststeuerung in transportnetzen. *Industrie Management*, 21(5):53–56, 2005.

[WLTG+08] B.-L. Wenning, A. Lukosius, A. Timm-Giel, C. Görg, and S. Tomic. Opportunistic distance-aware routing in multi-sink mobile wireless sensor networks. In *Proc. ICT-MobileSummit 2008*, pages CD–ROM, 8 pages, June 2008.

[WPTG06] B.-L. Wenning, D. Pesch, and A. Timm-Giel. A distributed routing approach for vehicle routing in logistic networks. In *Proc. 64th IEEE Vehicular Technology Conference*, pages CD–ROM, 5 pages, September 2006.

[WPTGG08] B.-L. Wenning, D. Pesch, A. Timm-Giel, and C. Görg. Environmental monitoring aware routing in wireless sensor networks. In *Proc. 10th IFIP Conference on Mobile and Wireless Communications Networks (MWCN)*, pages 5–16, September 2008.

[WPTGG09] B.-L. Wenning, D. Pesch, A. Timm-Giel, and C. Görg. Environmental monitoring aware routing: Making environmental sensor networks more robust. *Telecommunication Systems*, 43(1):3–11, 2009.

[WRTG$^+$07] B.-L. Wenning, H. Rekersbrink, A. Timm-Giel, C. Görg, and B. Scholz-Reiter. Autonomous control by means of distributed routing. In M. Hülsmann and K. Windt, editors, *Understanding Autonomous Cooperation and Control in Logistics - The Impact on Management, Information and Communication and Material Flow*, pages 325–335. Springer, 2007.

[WRTGG09] B.-L. Wenning, H. Rekersbrink, A. Timm-Giel, and C. Görg. Weighted multiplicative decision function for distributed routing in transport logistics. In *Proc. 2nd international conference on dynamics in logistics (LDIC 2009)*, page to appear, 2009.

[WTGG09] B.-L. Wenning, A. Timm-Giel, and C. Görg. A generic framework for context-aware routing and its implementation in wireless sensor networks. In *Mobilkommunikation - Technologien und Anwendungen, Vorträge der 14. ITG Fachtagung*, pages 53–58, May 2009.

[YF04] O. Younis and S. Fahmi. Heed: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on Mobile Computing*, 3(4):366–379, 2004.