TABLE III: Unified Benchmark Results of the Wireless Communication Technologies

| DISTANCE (meters) | MODULE | MESSAGE SIZE (Bytes) | AVERAGE ELAPSED (ms) | BEST ELAPSED (ms) | WORST ELAPSED (ms) | FAILED ATTEMPTS | SUCCESS RATE (%) | STD DEV (ms) |
|---|---|---|---|---|---|---|---|---|
| 1 | BLE | 16 | 2373,34 | 3678,57 | 2192,53 | 0 | 100 | 458,97 |
| 1 | BLE | 32 | 2324,68 | 2335,75 | 2295,52 | 0 | 100 | 12,23 |
| 1 | BLE | 64 | 2489,86 | 2525,76 | 2466,00 | 0 | 100 | 20,02 |
| 1 | BLE | 128 | 2905,03 | 2938,84 | 2878,74 | 0 | 100 | 17,58 |
| 1 | BLE | 255 | 3685,59 | 3754,65 | 3653,51 | 0 | 100 | 28,79 |
| 1 | BLUETOOTH | 16 | 4382,54 | 4551,87 | 4292,64 | 1 | 75 | 146,74 |
| 1 | BLUETOOTH | 32 | 4407,73 | 4425,71 | 4398,01 | 0 | 100 | 12,72 |
| 1 | BLUETOOTH | 64 | 4601,46 | 4608,96 | 4592,61 | 0 | 100 | 7,50 |
| 1 | BLUETOOTH | 128 | 5015,25 | 5020,03 | 5012,08 | 0 | 100 | 3,47 |
| 1 | BLUETOOTH | 255 | 5847,14 | 5850,49 | 5843,15 | 0 | 100 | 3,40 |
| 1 | NRF24L01 | 16 | 2124,35 | 2134,84 | 2111,07 | 0 | 100 | 7,53 |
| 1 | NRF24L01 | 32 | 2202,87 | 2211,93 | 2197,02 | 0 | 100 | 5,11 |
| 1 | NRF24L01 | 64 | 2357,03 | 2362,50 | 2352,33 | 0 | 100 | 3,44 |
| 1 | NRF24L01 | 128 | 2669,76 | 2676,42 | 2664,47 | 0 | 100 | 3,73 |
| 1 | NRF24L01 | 255 | 3290,90 | 3293,34 | 3288,90 | 0 | 100 | 1,61 |
| 1 | RF | 16 | 2625,67 | 2631,91 | 2618,03 | 0 | 100 | 5,05 |
| 1 | RF | 32 | 2844,48 | 2849,24 | 2839,96 | 0 | 100 | 3,34 |
| 1 | RF | 64 | 3499,99 | 3504,23 | 3496,46 | 1 | 90 | 2,97 |
| 1 | RF | 128 | 4691,67 | 4693,56 | 4690,42 | 5 | 50 | 1,24 |
| 1 | RF | 255 | 7054,72 | 7057,61 | 7050,25 | 5 | 50 | 2,83 |
| 1 | XBEE | 16 | 135,97 | 141,83 | 130,20 | 0 | 100 | 4,83 |
| 1 | XBEE | 32 | 2902,92 | 9520,18 | 211,14 | 0 | 100 | 4429,53 |
| 1 | XBEE | 64 | 2506,03 | 7619,61 | 323,46 | 0 | 100 | 3473,22 |
| 1 | XBEE | 128 | 706,45 | 706,45 | 706,45 | 3 | 25 | 0,00 |
| 1 | XBEE | 255 | 6100,45 | 7769,95 | 4430,94 | 2 | 50 | 2361,04 |
| 1 | LORA | 16 | 5060,96 | 5064,84 | 5055,29 | 1 | 75 | 5,02 |
| 1 | LORA | 32 | 5483,37 | 5487,15 | 5479,25 | 0 | 100 | 3,31 |
| 1 | LORA | 64 | 6575,92 | 6579,63 | 6569,58 | 0 | 100 | 4,38 |
| 1 | LORA | 128 | 8462,71 | 8465,36 | 8458,80 | 0 | 100 | 3,03 |
| 1 | LORA | 255 | 12189,11 | 12193,06 | 12185,73 | 1 | 75 | 3,70 |
| 8 | BLE | 16 | 2221,52 | 2247,74 | 2191,26 | 0 | 100 | 17,30 |
| 8 | BLE | 32 | 2297,86 | 2346,18 | 2282,28 | 0 | 100 | 18,42 |
| 8 | BLE | 64 | 2471,36 | 2511,28 | 2433,48 | 0 | 100 | 26,84 |
| 8 | BLE | 128 | 2973,45 | 3127,24 | 2840,96 | 0 | 100 | 89,26 |
| 8 | BLE | 255 | 3671,95 | 3866,10 | 3592,24 | 0 | 100 | 80,83 |
| 8 | BLUETOOTH | 16 | 4315,41 | 4484,12 | 4277,51 | 0 | 100 | 60,39 |
| 8 | BLUETOOTH | 32 | 4399,30 | 4410,78 | 4394,70 | 0 | 100 | 4,53 |
| 8 | BLUETOOTH | 64 | 4606,98 | 4622,12 | 4589,39 | 0 | 100 | 10,55 |
| 8 | BLUETOOTH | 128 | 5020,82 | 5038,48 | 5008,04 | 0 | 100 | 10,00 |
| 8 | BLUETOOTH | 255 | 5844,83 | 5853,88 | 5837,29 | 0 | 100 | 6,65 |
| 8 | NRF24L01 | 16 | 2129,10 | 2149,09 | 2121,69 | 0 | 100 | 8,08 |
| 8 | NRF24L01 | 32 | 2204,85 | 2214,73 | 2198,62 | 0 | 100 | 5,20 |
| 8 | NRF24L01 | 64 | 2358,07 | 2362,36 | 2355,61 | 0 | 100 | 2,31 |
| 8 | NRF24L01 | 128 | 2669,94 | 2674,47 | 2665,48 | 0 | 100 | 3,26 |
| 8 | NRF24L01 | 255 | 3289,87 | 3293,95 | 3285,80 | 0 | 100 | 2,68 |
| 8 | RF | 16 | 2624,03 | 2632,06 | 2614,55 | 1 | 90 | 7,06 |
| 8 | RF | 32 | 2844,60 | 2849,97 | 2841,84 | 0 | 100 | 2,44 |
| 8 | RF | 64 | 3499,34 | 3501,78 | 3496,46 | 2 | 80 | 1,89 |

Table III continued from previous page

| DISTANCE (meters) | MODULE | MESSAGE SIZE (Bytes) | AVERAGE ELAPSED (ms) | BEST ELAPSED (ms) | WORST ELAPSED (ms) | FAILED ATTEMPTS | SUCCESS RATE (%) | STD DEV (ms) |
|---|---|---|---|---|---|---|---|---|
| 8 | RF | 128 | 4690,53 | 4694,65 | 4689,05 | 5 | 50 | 2,34 |
| 8 | RF | 255 | 7055,16 | 7056,94 | 7053,57 | 3 | 70 | 1,36 |
| 8 | XBEE | 16 | 141,05 | 151,31 | 128,93 | 2 | 80 | 9,85 |
| 8 | XBEE | 32 | 200,56 | 211,88 | 194,69 | 2 | 80 | 6,21 |
| 8 | XBEE | 64 | 1417,77 | 9037,31 | 339,74 | 1 | 90 | 2865,36 |
| 8 | XBEE | 128 | 713,84 | 724,08 | 705,98 | 3 | 70 | 7,30 |
| 8 | XBEE | 255 | 1392,89 | 1397,19 | 1386,62 | 7 | 30 | 5,55 |
| 8 | LORA | 16 | 5061,07 | 5068,04 | 5054,04 | 0 | 100 | 4,48 |
| 8 | LORA | 32 | 5482,76 | 5488,42 | 5478,32 | 0 | 100 | 2,89 |
| 8 | LORA | 64 | 6578,88 | 6583,26 | 6573,54 | 0 | 100 | 3,21 |
| 8 | LORA | 128 | 8464,05 | 8468,97 | 8460,13 | 0 | 100 | 2,88 |
| 8 | LORA | 255 | 12187,28 | 12192,06 | 12183,65 | 0 | 100 | 2,68 |
| 16 | BLE | 16 | 2303,03 | 2376,45 | 2231,91 | 0 | 100 | 47,04 |
| 16 | BLE | 32 | 2365,07 | 2470,07 | 2315,85 | 0 | 100 | 46,78 |
| 16 | BLE | 64 | 2533,73 | 2585,83 | 2476,35 | 0 | 100 | 29,68 |
| 16 | BLE | 128 | 2930,26 | 3023,57 | 2841,00 | 0 | 100 | 63,80 |
| 16 | BLE | 255 | 3676,67 | 3745,90 | 3639,44 | 0 | 100 | 38,10 |
| 16 | BLUETOOTH | 16 | 4316,63 | 4453,82 | 4271,81 | 0 | 100 | 51,04 |
| 16 | BLUETOOTH | 32 | 4400,43 | 4426,38 | 4386,83 | 0 | 100 | 11,02 |
| 16 | BLUETOOTH | 64 | 4605,50 | 4621,88 | 4589,69 | 0 | 100 | 10,32 |
| 16 | BLUETOOTH | 128 | 5020,14 | 5034,83 | 5010,58 | 0 | 100 | 7,49 |
| 16 | BLUETOOTH | 255 | 5844,37 | 5864,31 | 5836,29 | 1 | 90 | 8,16 |
| 16 | NRF24L01 | 16 | 2128,55 | 2139,73 | 2113,66 | 0 | 100 | 8,70 |
| 16 | NRF24L01 | 32 | 2204,87 | 2208,68 | 2201,53 | 0 | 100 | 2,27 |
| 16 | NRF24L01 | 64 | 2358,91 | 2363,86 | 2353,76 | 0 | 100 | 3,10 |
| 16 | NRF24L01 | 128 | 2670,11 | 2673,43 | 2666,49 | 0 | 100 | 2,20 |
| 16 | NRF24L01 | 255 | 3290,12 | 3295,04 | 3285,75 | 0 | 100 | 2,60 |
| 16 | RF | 16 | 2620,36 | 2631,17 | 2613,66 | 0 | 100 | 5,73 |
| 16 | RF | 32 | 2845,43 | 2852,59 | 2841,67 | 1 | 90 | 3,14 |
| 16 | RF | 64 | 3499,81 | 3502,12 | 3495,43 | 5 | 50 | 2,71 |
| 16 | RF | 128 | 4688,32 | 4694,56 | 4685,18 | 4 | 60 | 3,49 |
| 16 | RF | 255 | 7055,22 | 7058,38 | 7052,00 | 5 | 50 | 2,60 |
| 16 | XBEE | 16 | 1240,76 | 8497,45 | 128,92 | 1 | 90 | 2744,55 |
| 16 | XBEE | 32 | 1361,60 | 7104,52 | 204,66 | 1 | 90 | 2263,89 |
| 16 | XBEE | 64 | 1459,65 | 9424,69 | 335,94 | 1 | 90 | 3004,38 |
| 16 | XBEE | 128 | 711,12 | 723,53 | 692,70 | 3 | 70 | 10,71 |
| 16 | XBEE | 255 | 1377,14 | 1377,99 | 1376,69 | 7 | 30 | 0,74 |
| 16 | LORA | 16 | 5061,41 | 5070,56 | 5054,21 | 0 | 100 | 5,37 |
| 16 | LORA | 32 | 5482,49 | 5490,49 | 5477,32 | 0 | 100 | 5,06 |
| 16 | LORA | 64 | 6575,57 | 6579,80 | 6571,95 | 0 | 100 | 2,33 |
| 16 | LORA | 128 | 8463,04 | 8466,75 | 8459,65 | 0 | 100 | 2,69 |
| 16 | LORA | 255 | 12187,48 | 12192,03 | 12180,80 | 0 | 100 | 3,59 |
| 32 | BLUETOOTH | 16 | 4323,42 | 4487,60 | 4284,09 | 0 | 100 | 58,74 |
| 32 | BLUETOOTH | 32 | 4402,40 | 4430,73 | 4378,72 | 0 | 100 | 15,76 |
| 32 | BLUETOOTH | 64 | 4608,69 | 4626,72 | 4599,49 | 0 | 100 | 8,29 |
| 32 | BLUETOOTH | 128 | 5026,98 | 5038,91 | 5013,23 | 0 | 100 | 7,81 |
| 32 | BLUETOOTH | 255 | 5861,59 | 5884,53 | 5840,27 | 0 | 100 | 14,98 |
| 32 | NRF24L01 | 16 | 2133,49 | 2146,09 | 2122,35 | 0 | 100 | 8,54 |
| 32 | NRF24L01 | 32 | 2208,39 | 2218,52 | 2201,29 | 0 | 100 | 5,61 |
| 32 | NRF24L01 | 64 | 2357,99 | 2361,40 | 2352,63 | 0 | 100 | 2,61 |

**Table III continued from previous page**

| DISTANCE (meters) | MODULE | MESSAGE SIZE (Bytes) | AVERAGE ELAPSED (ms) | BEST ELAPSED (ms) | WORST ELAPSED (ms) | FAILED ATTEMPTS | SUCCESS RATE (%) | STD DEV (ms) |
|---|---|---|---|---|---|---|---|---|
| 32 | NRF24L01 | 128 | 2672,19 | 2677,91 | 2667,68 | 0 | 100 | 2,68 |
| 32 | NRF24L01 | 255 | 3298,41 | 3315,60 | 3289,91 | 0 | 100 | 8,80 |
| 32 | RF | 16 | 2622,35 | 2633,40 | 2614,11 | 0 | 100 | 6,29 |
| 32 | RF | 32 | 2844,53 | 2846,92 | 2841,34 | 1 | 90 | 1,93 |
| 32 | RF | 64 | 3500,18 | 3502,78 | 3498,15 | 5 | 50 | 2,13 |
| 32 | RF | 128 | 4689,71 | 4693,02 | 4686,17 | 4 | 60 | 2,49 |
| 32 | RF | 255 | 7055,67 | 7059,64 | 7050,65 | 4 | 60 | 2,93 |
| 32 | XBEE | 16 | 2115,79 | 8741,72 | 132,35 | 2 | 80 | 3685,55 |
| 32 | XBEE | 32 | 1109,25 | 8347,55 | 195,13 | 1 | 90 | 2714,38 |
| 32 | XBEE | 64 | 2010,25 | 7702,04 | 332,86 | 1 | 90 | 3057,68 |
| 32 | XBEE | 128 | 2200,47 | 9186,12 | 705,47 | 3 | 70 | 3164,66 |
| 32 | XBEE | 255 | 1717,91 | 1717,91 | 1717,91 | 9 | 10 | 0,00 |
| 32 | LORA | 16 | 5059,01 | 5072,83 | 5050,56 | 0 | 100 | 6,52 |
| 32 | LORA | 32 | 5482,09 | 5490,21 | 5476,47 | 0 | 100 | 4,68 |
| 32 | LORA | 64 | 6575,96 | 6579,82 | 6573,71 | 0 | 100 | 1,87 |
| 32 | LORA | 128 | 8461,82 | 8465,15 | 8459,26 | 0 | 100 | 1,83 |
| 32 | LORA | 255 | 12185,42 | 12189,58 | 12181,67 | 0 | 100 | 2,84 |
| 64 | BLUETOOTH | 16 | 4349,28 | 4564,40 | 4311,69 | 0 | 100 | 77,08 |
| 64 | BLUETOOTH | 32 | 4416,23 | 4444,80 | 4395,06 | 0 | 100 | 17,30 |
| 64 | BLUETOOTH | 64 | 4633,67 | 4670,44 | 4603,22 | 0 | 100 | 18,51 |
| 64 | BLUETOOTH | 128 | 5059,98 | 5097,20 | 5026,30 | 0 | 100 | 22,35 |
| 64 | BLUETOOTH | 255 | 5909,00 | 5963,59 | 5864,33 | 0 | 100 | 26,77 |
| 64 | NRF24L01 | 16 | 2137,94 | 2144,99 | 2122,19 | 0 | 100 | 6,20 |
| 64 | NRF24L01 | 32 | 2205,76 | 2212,68 | 2200,25 | 0 | 100 | 3,90 |
| 64 | NRF24L01 | 64 | 2358,77 | 2360,61 | 2357,23 | 0 | 100 | 1,46 |
| 64 | NRF24L01 | 128 | 2670,40 | 2674,19 | 2666,88 | 0 | 100 | 2,38 |
| 64 | NRF24L01 | 255 | 3289,44 | 3295,10 | 3285,13 | 0 | 100 | 2,96 |
| 64 | RF | 16 | 2625,81 | 2633,00 | 2618,24 | 0 | 100 | 5,54 |
| 64 | RF | 32 | 2842,35 | 2848,01 | 2838,57 | 0 | 100 | 3,41 |
| 64 | RF | 64 | 3499,93 | 3502,92 | 3497,15 | 5 | 50 | 2,10 |
| 64 | RF | 128 | 4688,12 | 4690,69 | 4685,16 | 4 | 60 | 2,32 |
| 64 | RF | 255 | 7056,03 | 7056,82 | 7054,46 | 7 | 30 | 1,37 |
| 64 | XBEE | 16 | 959,08 | 7101,80 | 130,39 | 1 | 90 | 2308,24 |
| 64 | XBEE | 32 | 2242,40 | 9039,76 | 194,96 | 1 | 90 | 3684,41 |
| 64 | XBEE | 64 | 1818,06 | 7706,86 | 324,30 | 1 | 90 | 2962,62 |
| 64 | XBEE | 128 | 2203,54 | 9212,31 | 696,21 | 3 | 70 | 3174,34 |
| 64 | XBEE | 255 | 6600,43 | 12546,07 | 1861,06 | 6 | 40 | 4989,70 |
| 64 | LORA | 16 | 5064,33 | 5070,23 | 5051,33 | 0 | 100 | 6,06 |
| 64 | LORA | 32 | 5483,37 | 5488,84 | 5480,04 | 0 | 100 | 2,89 |
| 64 | LORA | 64 | 6606,40 | 6706,72 | 6566,78 | 0 | 100 | 51,18 |
| 64 | LORA | 128 | 8452,72 | 8466,59 | 8430,61 | 0 | 100 | 12,84 |
| 64 | LORA | 255 | 12176,45 | 12181,31 | 12166,95 | 0 | 100 | 4,01 |
| 128 | NRF24L01 | 16 | 2126,90 | 2138,54 | 2113,72 | 0 | 100 | 9,41 |
| 128 | NRF24L01 | 32 | 2202,62 | 2207,34 | 2198,48 | 0 | 100 | 2,73 |
| 128 | NRF24L01 | 64 | 2358,18 | 2362,47 | 2354,43 | 0 | 100 | 2,87 |
| 128 | NRF24L01 | 128 | 2669,69 | 2673,60 | 2666,92 | 0 | 100 | 1,88 |
| 128 | NRF24L01 | 255 | 3289,56 | 3293,50 | 3286,94 | 0 | 100 | 2,27 |
| 128 | RF | 16 | 2626,92 | 2632,77 | 2619,74 | 1 | 90 | 4,12 |
| 128 | RF | 32 | 2843,25 | 2845,96 | 2839,91 | 1 | 90 | 2,19 |
| 128 | RF | 64 | 3498,72 | 3502,52 | 3496,90 | 5 | 50 | 2,30 |

**Table III continued from previous page**

| DISTANCE (meters) | MODULE | MESSAGE SIZE (Bytes) | AVERAGE ELAPSED (ms) | BEST ELAPSED (ms) | WORST ELAPSED (ms) | FAILED ATTEMPTS | SUCCESS RATE (%) | STD DEV (ms) |
|---|---|---|---|---|---|---|---|---|
| 128 | RF | 128 | 4689,85 | 4691,91 | 4687,20 | 4 | 60 | 1,64 |
| 128 | RF | 255 | 7054,31 | 7057,48 | 7051,23 | 3 | 70 | 2,24 |
| 128 | XBEE | 16 | 133,90 | 139,94 | 129,87 | 3 | 70 | 3,69 |
| 128 | XBEE | 32 | 278,41 | 680,92 | 205,37 | 3 | 70 | 177,55 |
| 128 | XBEE | 64 | 570,65 | 1266,80 | 336,92 | 2 | 80 | 347,99 |
| 128 | XBEE | 128 | 707,65 | 717,71 | 695,73 | 3 | 70 | 7,94 |
| 128 | XBEE | 255 | 7231,62 | 13199,86 | 3780,98 | 5 | 50 | 4179,17 |
| 128 | LORA | 16 | 5058,91 | 5063,87 | 5053,01 | 0 | 100 | 3,45 |
| 128 | LORA | 32 | 5483,23 | 5489,57 | 5479,02 | 0 | 100 | 3,93 |
| 128 | LORA | 64 | 6578,37 | 6585,46 | 6574,90 | 0 | 100 | 3,04 |
| 128 | LORA | 128 | 8461,90 | 8467,29 | 8457,73 | 0 | 100 | 3,03 |
| 128 | LORA | 255 | 12188,05 | 12192,24 | 12184,62 | 0 | 100 | 3,17 |
| 256 | RF | 16 | 2627,44 | 2634,18 | 2614,01 | 0 | 100 | 5,12 |
| 256 | RF | 32 | 2844,84 | 2851,19 | 2839,85 | 1 | 97 | 3,49 |
| 256 | RF | 64 | 3499,11 | 3502,90 | 3494,90 | 11 | 63 | 2,24 |
| 256 | RF | 128 | 4691,22 | 4697,02 | 4685,92 | 10 | 67 | 2,75 |
| 256 | RF | 255 | 7055,64 | 7059,71 | 7051,38 | 13 | 57 | 2,68 |
| 256 | XBEE | 16 | 1106,42 | 9265,95 | 127,57 | 8 | 73 | 2586,70 |
| 256 | XBEE | 32 | 1379,77 | 9098,16 | 190,48 | 6 | 80 | 2829,21 |
| 256 | XBEE | 64 | 1209,45 | 8743,09 | 323,22 | 7 | 77 | 2298,11 |
| 256 | XBEE | 128 | 913,00 | 1206,61 | 701,56 | 14 | 53 | 235,52 |
| 256 | XBEE | 255 | 1383,34 | 1383,34 | 1383,34 | 29 | 3 | 0,00 |
| 256 | LORA | 16 | 5064,57 | 5075,59 | 5052,44 | 0 | 100 | 5,31 |
| 256 | LORA | 32 | 5483,12 | 5490,88 | 5474,78 | 0 | 100 | 3,49 |
| 256 | LORA | 64 | 6577,36 | 6582,81 | 6572,36 | 0 | 100 | 2,90 |
| 256 | LORA | 128 | 8463,24 | 8470,06 | 8457,78 | 0 | 100 | 3,12 |
| 256 | LORA | 255 | 12187,99 | 12192,77 | 12183,94 | 0 | 100 | 2,25 |
| 1024 | LORA | 16 | 5059,96 | 5080,23 | 5050,90 | 0 | 100 | 6,72 |
| 1024 | LORA | 32 | 5482,44 | 5489,50 | 5474,69 | 0 | 100 | 3,25 |
| 1024 | LORA | 64 | 6576,47 | 6582,01 | 6569,19 | 0 | 100 | 3,19 |
| 1024 | LORA | 128 | 8461,47 | 8465,52 | 8456,17 | 0 | 100 | 2,83 |
| 1024 | LORA | 255 | 12186,79 | 12194,27 | 12178,13 | 0 | 100 | 3,07 |
| 2048 | LORA | 16 | 5064,69 | 5074,16 | 5053,64 | 0 | 100 | 6,26 |
| 2048 | LORA | 32 | 5484,93 | 5493,51 | 5478,80 | 0 | 100 | 4,12 |
| 2048 | LORA | 64 | 6577,53 | 6581,86 | 6573,06 | 0 | 100 | 2,55 |
| 2048 | LORA | 128 | 8463,60 | 8469,14 | 8457,06 | 0 | 100 | 3,00 |
| 2048 | LORA | 255 | 12187,06 | 12192,41 | 12182,17 | 0 | 100 | 2,67 |