

SNUS projekat - tema 2 konzistentan sistem

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Sadržaj

1	Sažetak	3
2	Specifikacija zadatka (rezime zahteva)	3
3	Arhitektura i raspored projekata	3
3.1	Struktura rešenja	3
3.2	Endpointi i portovi	4
3.3	Tok izvršavanja	4
4	Contracti servisa i DTO tipovi	4
4.1	ISensorService (System.ServiceModel)	4
4.2	ICoordinatorService (System.ServiceModel)	5
4.3	DTO primeri	5
5	Model podataka i EF Core	6
5.1	Šema	6
5.2	DbContext	6
6	Senzorski servisi i sampler	6
6.1	Pozadinski sampler (po hostu)	6
6.2	Implementacija servisa	7
7	Koordinator (poravnanje)	8
7.1	Ponašanje	8
7.2	Koordinator	8
8	Klijent (kvorum čitanja)	9
8.1	Algoritam	9
8.2	Podešavanje tolerancije (bez rekompajliranja)	9
9	Testovi	9
9.1	Šta se testira	9
9.2	Testni kod	9
10	Build i pokretanje	12
10.1	Preduslovi	12
10.2	Komande	12
10.3	Pokretanje testova	13
11	Provera rada i inspekcija baza	13
11.1	GUI alat	13
12	Kvorum i replika	13
13	CAP teorema (primena na projekat)	13

1 Sažetak

Ovaj dokument služi kao dokumentacija za SNUS projekat. Sistem modeluje tri nezavisna temperaturna senzora (S1–S3), svaki sa sopstvenom bazom podataka; koordinator servis koji vrši poravnanje između senzora; i klijenta koji implementira kvorum čitanja. Serverske SOAP krajnje tačke se hostuju uz **CoreWCF**, dok klijent koristi **WCF (System.ServiceModel)**; perzistencija je **EF Core + SQLite**.

Osnova projekta

- Tri senzorska servisa (**ISensorService**) preko SOAP/HTTP (**BasicHttpBinding**), svaki piše merenja u sopstvenu SQLite bazu na 1–10 s (nasumično).
- Klijent primenjuje kvorum čitanja: rezultat se prihvata ako su najmanje *dva* poslednja očitavanja u okviru tolerancije t oko srednje vrednosti; u suprotnom, pokreće se poravnanje.
- Koordinator servis: periodično (svakog minuta) poravnanje; klijentska čitanja čekaju dok je poravnanje u toku; poslednji red u sve tri tabele postaje isti (prosečna vrednost poslednjih merenja).

2 Specifikacija zadatka (rezime zahteva)

Zahtevi projekta glase ukratko:

1. Napraviti WCF aplikaciju sa **3 senzora** koji na svakih 1–10 s mere temperaturu i upisuju u **odvojene baze**.
2. Napraviti klijenta koji preko WCF-a čita vrednosti i prihvata rezultat samo ako je bar **2 od 3** u intervalu ± 5 oko srednje vrednosti; inače **pokreće poravnanje**.
3. **Svakog minuta**, nezavisno od klijenta, izvršiti poravnanje tako da **poslednja vrednost** u sve tri tabele bude **ista** i jednaka proseku poslednjih merenja; **čitanja čekaju** dok poravnanje traje.
4. **Obrazložiti** kvorum repliku i CAP teoremu u kontekstu projekta.
5. Napisati **detaljnu dokumentaciju** (opis projekta i implementacije).

3 Arhitektura i raspored projekata

3.1 Struktura rešenja

- **Shared.Contracts**: WCF ugovori (**System.ServiceModel**) i DTO tipovi.
- **Sensor.Service**: EF Core entiteti/kontekst; pozadinski *sampler*; implementacija **ISensorService**.
- **Sensor.S1.Host**, **Sensor.S2.Host**, **Sensor.S3.Host**: CoreWCF hostovi koji izlažu `/sensor`.
- **Coordinator.Host**: CoreWCF host koji izlaže `/coord` i sadrži *minute scheduler*.
- **Client.CLI**: konzolni WCF klijent (**System.ServiceModel**) koji poziva oba servisa.

3.2 Endpointi i portovi

Host	Osnovni URL	Endpoint / Ugovor
Sensor S1	http://localhost:5011	/sensor (ISensorService)
Sensor S2	http://localhost:5012	/sensor (ISensorService)
Sensor S3	http://localhost:5013	/sensor (ISensorService)
Coordinator	http://localhost:5020	/coord (ICoordinatorService)

3.3 Tok izvršavanja

1. Svaki senzor pokreće *sampler* koji na 1–10 s upisuje merenje u sopstvenu bazu (SQLite).
2. Klijent uzima poslednje vrednosti sa S1–S3 i meri kvorum (tolerancija t). Ako su barem 2 od 3 u okviru t oko srednje vrednosti, prihvata se prosek inlajera (merenje unutar zadate tolerancije).
3. Ako nema kvoruma, klijent poziva `ReconcileAsync`. Koordinator zaključava globalno, čita poslednje vrednosti, računa prosek i na svakom senzoru poziva `AppendReconciled` — posle čega je poslednji red u sve tri tabele isti.

4 Contracti servisa i DTO tipovi

4.1 ISensorService (System.ServiceModel)

```
using System;
using System.ServiceModel;

namespace Shared.Contracts
{
    [ServiceContract(Name="ISensorService", Namespace="http://tempuri.org/")]
    public interface ISensorService
    {
        [OperationContract(Action="http://tempuri.org/ISensorService/Start", ReplyAction="*")]
        void Start();

        [OperationContract(Action="http://tempuri.org/ISensorService/Stop", ReplyAction="*")]
        void Stop();

        [OperationContract(Action="http://tempuri.org/ISensorService/GetLatest", ReplyAction="*")]
        double GetLatest();

        [OperationContract(Action="http://tempuri.org/ISensorService/GetSnapshot", ReplyAction="*")]
        SensorSnapshot GetSnapshot(TimeSpan lookback);

        [OperationContract(Action="http://tempuri.org/ISensorService/AppendReconciled", ReplyAction="*")]
        void AppendReconciled(double value);
    }
}
```

4.2 ICoordinatorService (System.ServiceModel)

```
using System.ServiceModel;
using System.Threading.Tasks;

namespace Shared.Contracts
{
    [ServiceContract(Name="ICoordinatorService", Namespace="http://tempuri.org/")]
    public interface ICoordinatorService
    {
        [OperationContract(Action="http://tempuri.org/ICoordinatorService/ReconcileAsync",
            ReplyAction="*")]
        Task<ReconResult> ReconcileAsync();

        [OperationContract(Action="http://tempuri.org/ICoordinatorService/
            IsReconInProgress", ReplyAction="*")]
        bool IsReconInProgress();
    }
}
```

4.3 DTO primeri

```
using System;
using System.Runtime.Serialization;

[DataContract]
public class SensorSnapshot {
    [DataMember(Order=1)] public string SensorId { get; set; } = "";
    [DataMember(Order=2)] public DateTimeOffset From { get; set; }
    [DataMember(Order=3)] public DateTimeOffset To { get; set; }
    [DataMember(Order=4)] public double[] Values { get; set; } = Array.Empty<double>();
    public SensorSnapshot() { }
}

[DataContract]
public class ReconResult {
    [DataMember(Order=1)] public bool Success { get; set; }
    [DataMember(Order=2)] public DateTimeOffset At { get; set; }
    [DataMember(Order=3)] public double AveragedValue { get; set; }
    [DataMember(Order=4)] public string Message { get; set; } = "";
    public ReconResult() { }
    public ReconResult(bool ok, DateTimeOffset at, double avg, string msg)
    { Success = ok; At = at; AveragedValue = avg; Message = msg; }
}
```

5 Model podataka i EF Core

5.1 Šema

```
using System.ComponentModel.DataAnnotations;
using System.ComponentModel.DataAnnotations.Schema;

[Table("SensorReadings")]
public class SensorReading {
    [Key] public int Id { get; set; }
    [Required, MaxLength(8)] public string SensorId { get; set; } = "";
    public DateTimeOffset Timestamp { get; set; }
    public double TemperatureC { get; set; }
    public bool IsReconciled { get; set; }
}
```

5.2 DbContext

```
using Microsoft.EntityFrameworkCore;
using Microsoft.EntityFrameworkCore.Storage.ValueConversion;

public class SensorDbContext : DbContext {
    public SensorDbContext(DbContextOptions<SensorDbContext> options) : base(options) { }

    public DbSet<SensorReading> Readings => Set<SensorReading>();

    protected override void OnModelCreating(ModelBuilder modelBuilder) {
        var tsConverter = new DateTimeOffsetToBinaryConverter();
        modelBuilder.Entity<SensorReading>()
            .Property(r => r.Timestamp)
            .HasConversion(tsConverter);
        modelBuilder.Entity<SensorReading>()
            .HasIndex(r => r.Timestamp);
    }
}
```

Datoteke baza Svaki host čuva SQLite bazu u sopstvenom `./data/` direktorijumu (pored izvršnog fajla). Šema se kreira pri startu (`EnsureCreated()`).

6 Senzorski servisi i sampler

6.1 Pozadinski sampler (po hostu)

```
public class SamplerWorker : BackgroundService {
    private readonly ILogger<SamplerWorker> _log;
    private readonly IServiceProvider _sp;
    private readonly string _sensorId;
    private readonly ISamplingSwitch _switch;
    private readonly Random _rng = new();

    protected override async Task ExecuteAsync(CancellationToken ct) {
        using (var scope = _sp.CreateScope())
            await scope.ServiceProvider.GetRequiredService<SensorDbContext>()
                .Database.EnsureCreatedAsync(ct);
    }
}
```

```

while (!ct.IsCancellationRequested) {
    await Task.Delay(TimeSpan.FromSeconds(_rng.Next(1, 11)), ct);
    if (!_switch.Enabled) continue;

    using var scope = _sp.CreateScope();
    var db = scope.ServiceProvider.GetRequiredService<SensorDbContext>();
    var value = 20.0 + (_rng.NextDouble() - 0.5) * 0.8; // blaga varijacija
    db.Readings.Add(new SensorReading {
        SensorId = _sensorId, Timestamp = DateTimeOffset.UtcNow,
        TemperatureC = value, IsReconciled = false
    });
    await db.SaveChangesAsync(ct);
    _log.LogInformation("{SensorId} wrote {Value:F2} C", _sensorId, value);
}
}
}

```

6.2 Implementacija servisa

```

public class SensorService : ISensorService {
    private readonly string _sensorId;
    private readonly SensorDbContext _db;
    private readonly ISamplingSwitch _switch;

    public SensorService(string sensorId, SensorDbContext db, ISamplingSwitch
        samplingSwitch) {
        _sensorId = sensorId; _db = db; _switch = samplingSwitch;
    }

    public void Start() => _switch.Enabled = true;
    public void Stop() => _switch.Enabled = false;

    public double GetLatest() =>
        _db.Readings.OrderByDescending(r => r.Timestamp)
            .Select(r => (double?)r.TemperatureC)
            .FirstOrDefault() ?? 20.0;

    public SensorSnapshot GetSnapshot(TimeSpan lookback) {
        var now = DateTimeOffset.UtcNow; var from = now - lookback;
        var values = _db.Readings.Where(r => r.Timestamp >= from && r.Timestamp <= now)
            .OrderBy(r => r.Timestamp)
            .Select(r => r.TemperatureC)
            .ToArray();
        return new SensorSnapshot { SensorId = _sensorId, From = from, To = now, Values =
            values };
    }

    public void AppendReconciled(double value) {
        _db.Readings.Add(new SensorReading {
            SensorId = _sensorId, Timestamp = DateTimeOffset.UtcNow,
            TemperatureC = value, IsReconciled = true
        });
        _db.SaveChanges();
    }
}

```

7 Koordinator (poravnanje)

7.1 Ponašanje

- **IsReconInProgress**: izlaže globalno stanje poravnanja (klijenti čekaju dok je **true**).
- **ReconcileAsync**: zaštićeno sa **SemaphoreSlim**. Čita poslednje vrednosti S1–S3, računa prosek i upisuje ga u sve tri baze (**AppendReconciled**).
- **ReconcilerWorker**: *HostedService* koji okida poravnanje svake minute.

7.2 Koordinator

```
public class CoordinatorService : ICoordinatorService {
    private readonly ILogger<CoordinatorService> _log;
    private readonly ChannelFactory<ISensorService>[] _sensors;
    private readonly SemaphoreSlim _mutex = new(1, 1);
    private volatile bool _inProgress;

    public CoordinatorService(ILogger<CoordinatorService> log,
                             IEnumerable<ChannelFactory<ISensorService>> sensors) {
        _log = log; _sensors = sensors.ToArray();
        _log.LogInformation("Sensors registered = {Count}", _sensors.Length);
    }

    public bool IsReconInProgress() => _inProgress;

    public async Task<ReconResult> ReconcileAsync() {
        await _mutex.WaitAsync();
        _inProgress = true;
        try {
            var ch1 = _sensors[0].CreateChannel();
            var ch2 = _sensors[1].CreateChannel();
            var ch3 = _sensors[2].CreateChannel();

            var x1 = ch1.GetLatest(); var x2 = ch2.GetLatest(); var x3 = ch3.GetLatest();
            var avg = (x1 + x2 + x3) / 3.0;
            ch1.AppendReconciled(avg); ch2.AppendReconciled(avg); ch3.AppendReconciled(avg);

            ((IClientChannel)ch1).Close(); ((IClientChannel)ch2).Close(); ((IClientChannel)
            ch3).Close();
            return new ReconResult(true, DateTimeOffset.UtcNow, avg, "Reconciled to average
            of latests.");
        } catch (Exception ex) {
            _log.LogError(ex, "Reconcile failed");
            return new ReconResult(false, DateTimeOffset.UtcNow, double.NaN, $"Reconcile
            failed: {ex.Message}");
        } finally {
            _inProgress = false; _mutex.Release();
        }
    }
}
```


8 Klijent (kvorum čitanja)

8.1 Algoritam

Za poslednje vrednosti x_1, x_2, x_3 računamo $\mu = \frac{x_1+x_2+x_3}{3}$. Sa tolerancijom t brojimo inlajere $\{x_i : |x_i - \mu| \leq t\}$. Ako ≥ 2 , prihvatamo prosek inlajera; inače čekamo (ako je u toku poravnanje) ili pozivamo `ReconcileAsync`, pa ponovo čitamo.

8.2 Podešavanje tolerancije (bez rekompajliranja)

```
# single-shot (podrazumevano t = 5.0)
dotnet run --project src/Client.CLI

# promena tolerancije i posmatranje u petlji (interval u ms)
dotnet run --project src/Client.CLI -- --tol 0.5 --watch --interval 3000
```

9 Testovi

Dodat je skup testova koji proveravaju: (1) da klijent **čeka** dok je poravnanje u toku (nema čitanja dok koordinator drži “in-progress” zastavicu), (2) pozitivan kvorum (*quorum hit*, bez poravnanja) i (3) *no-quorum* putanju (okida se poravnanje pa se ponovo čita).

9.1 Šta se testira

- **Čekanje tokom poravnanja:** dok je `IsReconInProgress()==true`, klijent ne zove senzore; tek po spuštanju zastavice radi jedno kružno čitanje.
- **Kvorum uspeva (bez poravnanja):** tri bliske vrednosti i tolerancija t daju najmanje $2/3$ inlajera; nema poziva `ReconcileAsync()`.
- **Nema kvoruma (sa poravnanjem):** divergentne vrednosti i mala tolerancija; klijent poziva `ReconcileAsync()`, sačeka i ponovi čitanje.

9.2 Testni kod

```
using System;
using System.Linq;
using System.Threading;
using System.Threading.Tasks;
using FluentAssertions;
using Shared.Contracts;
using Xunit;

namespace Client.Tests
{
    // Minimalne klijentske fasade
    public interface ISensorServiceClient
    {
        double GetLatest();
        void AppendReconciled(double value);
    }

    public interface ICoordinatorServiceClient
    {
        Task<ReconResult> ReconcileAsync();
    }
}
```

```

        bool IsReconInProgress();
    }

    // In-memory fakes
    public sealed class FakeSensor : ISensorServiceClient
    {
        private readonly Func<double> _get;
        public int ReadCount { get; private set; }
        public FakeSensor(Func<double> get) { _get = get; }
        public double GetLatest() { ReadCount++; return _get(); }
        public void AppendReconciled(double value) { }
    }

    public sealed class FakeCoordinator : ICoordinatorServiceClient
    {
        private readonly TimeSpan _reconDuration;
        private int _reconcileCalls;
        public volatile bool InProgress;
        public int ReconcileCalls => _reconcileCalls;

        public FakeCoordinator(bool startInProgress = false, TimeSpan? reconDuration =
null)
        {
            InProgress = startInProgress;
            _reconDuration = reconDuration ?? TimeSpan.FromMilliseconds(200);
        }

        public bool IsReconInProgress() => InProgress;

        public async Task<ReconResult> ReconcileAsync()
        {
            Interlocked.Increment(ref _reconcileCalls);
            InProgress = true;
            try
            {
                await Task.Delay(_reconDuration);
                return new ReconResult(true, DateTimeOffset.UtcNow, 0.0, "OK");
            }
            finally { InProgress = false; }
        }
    }

    public class QuorumAndReconcileTests
    {
        private static int SumReads(params ISensorServiceClient[] sensors)
        {
            var total = 0;
            foreach (var s in sensors)
                if (s is FakeSensor fs) total += fs.ReadCount;
            return total;
        }

        private static async Task<(bool accepted, double value, int readsBefore, int
readsAfter, int reconCalls)>
            RunClientOnceAsync(
                ICoordinatorServiceClient coord,
                ISensorServiceClient s1,
                ISensorServiceClient s2,

```

```

        ISensorServiceClient s3,
        double tol,
        CancellationToken ct = default)
    {
        // 1) cekaj dok je poravnanje u toku
        int readsBefore = SumReads(s1, s2, s3);
        while (coord.IsReconInProgress())
            await Task.Delay(25, ct);

        // 2) procitaj tri vrednosti
        var x1 = s1.GetLatest();
        var x2 = s2.GetLatest();
        var x3 = s3.GetLatest();

        var mean = (x1 + x2 + x3) / 3.0;
        var inliers = new[] { x1, x2, x3 }.Where(v => Math.Abs(v - mean) <= tol).
ToArray();

        if (inliers.Length >= 2)
        {
            var accepted = inliers.Average();
            int readsAfterA = SumReads(s1, s2, s3);
            return (true, accepted, readsBefore, readsAfterA, (coord as
FakeCoordinator)?.ReconcileCalls ?? 0);
        }

        // 3) nema kvoruma -> poravnanje
        var _ = await coord.ReconcileAsync();

        // 4) sacekaj da spusti zastavicu
        while (coord.IsReconInProgress())
            await Task.Delay(25, ct);

        // 5) ponovo procitaj
        x1 = s1.GetLatest(); x2 = s2.GetLatest(); x3 = s3.GetLatest();
        var accepted2 = new[] { x1, x2, x3 }.Average();
        int readsAfterB = SumReads(s1, s2, s3);

        return (true, accepted2, readsBefore, readsAfterB, (coord as
FakeCoordinator)?.ReconcileCalls ?? 0);
    }

    [Fact]
    public async Task
Client_Waits_While_Reconcile_In_Progress_No_Reads_Before_Gate_Opens()
    {
        var coord = new FakeCoordinator(startInProgress: true, reconDuration:
TimeSpan.FromMilliseconds(1));
        _ = Task.Run(async () => { await Task.Delay(300); coord.InProgress = false;
});

        var s1 = new FakeSensor(() => 20.0);
        var s2 = new FakeSensor(() => 20.1);
        var s3 = new FakeSensor(() => 20.2);

        var (accepted, _, readsBefore, readsAfter, reconCalls) =
            await RunClientOnceAsync(coord, s1, s2, s3, tol: 0.5);
    }

```

```

        readsBefore.Should().Be(0);
        readsAfter.Should().Be(3);
        reconCalls.Should().Be(0);
        accepted.Should().BeTrue();
    }

    [Fact]
    public async Task Client_Quorum_Hit_No_Reconcile()
    {
        var coord = new FakeCoordinator(startInProgress: false);
        var s1 = new FakeSensor(() => 20.0);
        var s2 = new FakeSensor(() => 20.1);
        var s3 = new FakeSensor(() => 20.2);

        var (accepted, value, _, readsAfter, reconCalls) =
            await RunClientOnceAsync(coord, s1, s2, s3, tol: 0.5);

        accepted.Should().BeTrue();
        readsAfter.Should().Be(3);
        reconCalls.Should().Be(0);
        value.Should().BeApproximately(20.05, 0.2);
    }

    [Fact]
    public async Task Client_NoQuorum_Triggers_Reconcile_Then_ReReads()
    {
        var coord = new FakeCoordinator(startInProgress: false, reconDuration:
        TimeSpan.FromMilliseconds(150));
        var s1 = new FakeSensor(() => 20.0);
        var s2 = new FakeSensor(() => 22.0);
        var s3 = new FakeSensor(() => 24.0);

        var (accepted, _, _, readsAfter, reconCalls) =
            await RunClientOnceAsync(coord, s1, s2, s3, tol: 0.3);

        reconCalls.Should().Be(1);
        readsAfter.Should().Be(6);
        accepted.Should().BeTrue();
    }
}

```

10 Build i pokretanje

10.1 Preduslovi

Instaliran .NET 8 SDK; SQLite je ugrađen (nema eksternog servera).

10.2 Komande

```

dotnet restore
dotnet build -c Debug

# senzori (tri terminala)
dotnet run --project src/Sensor.S1.Host
dotnet run --project src/Sensor.S2.Host

```

```
dotnet run --project src/Sensor.S3.Host

# koordinator
dotnet run --project src/Coordinator.Host

# klijent
dotnet run --project src/Client.CLI
```

10.3 Pokretanje testova

Testovi se nalaze u `tests/Client.Tests`. Preporučeno je da ih pokrenete nakon build-a:

```
# pokretanje celog test projekta
dotnet test tests/Client.Tests
```

11 Provera rada i inspekcija baza

11.1 GUI alat

Instalirajte *DB Browser for SQLite*, otvorite `s1.db`, `s2.db`, `s3.db` (obično pod `bin/Debug/net8.0/data/`), pogledajte tabelu `SensorReadings` i sortirajte po `Timestamp`. Posle poravnanja poslednji red treba da bude isti u sve tri baze (`IsReconciled=1`).

12 Kvorum i replika

Za tri replike usvajamo čitanje sa kvorumom $R = 2$: dovoljne su dve saglasne vrednosti (unutar tolerancije oko globalne sredine) da bi klijent prihvatio rezultat. Poravnanje je upis sa $W = 3$: prosečna poslednja vrednost se upisuje kao *poslednji* red u sve tri baze. Time obezbeđujemo da je posle poravnanja poslednja vrednost konzistentna i lako proverljiva.

13 CAP teorema (primena na projekat)

Kako postoje nezavisne usluge i mrežne pozive, particije su moguće. U trenutku poravnanja biramo **Konzistentnost** ispred **Dostupnosti** (čitamo tek kada se poravnanje završi). Van tog trenutka sistem nudi visoku dostupnost: svaki senzor može da odgovori, a klijent koristi kvorum čitanja da poveća pouzdanost rezultata. Periodično poravnanje obezbeđuje *eventualnu* konvergenciju, izgleda kao trenutna (atomska) promena poslednjeg reda u sve tri baze..